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LOCARCH SHELTER

Jean R. Saulnier, et al

Air Force Civil Engineering Center
Tyndall Air Force Base, Florida

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Final Report For Period December 1973 to August 1974

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The report describes the erection, field testing and disassembly of the LocArch air transportable aircraft shelter, manufactured by the Lockheed Georgia Co. Marietta, GA. The outcome of the shelter evaluation revealed the design concept to be basically sound but deficiencies existed in the arch panels and the end closures. An in depth analysis of the shelter components was conducted during the test program. The entire shelter system was subjected to simulated environmental tests to evalute its performance for possible world wide use.

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FORWORD

This report summarizes the shelter test program conducted between December 1973 and August 1974, Major Jean R. Saulnier was the Project Engineer. MSgt Earl T. Denny and MSgt Bernard D. McDonald conducted the field testing and data acquisition. Appreciation is extended to Mr Jim Hills Program Manager and Mr A. Nagrani Project Engineer, Lockheed Georgia Co. for their excellent cooperation during the fabrication phase of the LocArch shelter and the assistance rendered during the initial stages of the test program.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

JEAN R. SAULNIER, Major, USAF Project Engineer	CHURCH WATKINS JR., Lt Colonel, USAF Director of Field Technology
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ABSTRACT

The Air Force Civil Engineering Center (AFCEC) received an unsolicited proposal for a air transportable aircraft shelter from Lockheed Georgia Company and subsequently awarded a contract for a portion of the shelter. Although the shelter was designed to be 88 feet long, only 64 feet was procured for field testing and evaluation to be performed by AFCEC personnel. The test program was conducted between December 1973 and August 1974 and included multiple erections and disassemblies on various types of terrain and simulated environmental and load tests. The design concept proved to be satisfactory although several deficiencies were noted in the shelter components during the test program.

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SECTION I

INTRODUCTION

Air transportable mobility aircraft shelters have been under development within the Air Force since 1967, principally under the bare base program conducted at Wright-Patterson AFB under Aeronautical Systems Division (ASD) direction. The program emphasis was to provide a mobility shelter that could be packed inside containers that could be carried by C-130 aircraft. The shelters were required to be lightweight and erectable with minimum equipment and tools. The design challenges were formidable to provide the capability to erect an aircraft hanger that would accommodate the various size aircraft within the Air Force inventory. Several types of shelters were developed by ASD to respond to this requirement. In November 1972, the Air Force Civil Engineering Center (AFCEC) was appointed the "focal point" for the mobility shelter program within Air Force Systems Command and initiated a capability to field test various types of shelters. In December of 1972, an unsolicited proposal was received by AFCEC submitted by the Lockheed Georgia Company, a division of the Lockheed Aircraft Company. The new concept for a mobility aircraft shelter was found to have sufficient merit to pursue further negotiations with Lockheed Georgia. Contract negotiations were initiated in March of 1973 and a contract was awarded the first part of April 1973 to Lockheed in the amount of $99,500. The contract provided for a shelter 76 feet wide and 64 feet long. The end design of the Lockheed mobility shelter concept

was 88 feet; but, for the purposes of the proposed test program and in the interest of economy, only 64 feet of the shelter were procured. In addition to the basic arch assembly, one end wall and one container were to be provided. Although the complete shelter would be packaged in four containers, one container was all that the contract included for test purposes. The container was to be provided with International Standard Organization (ISO) fittings and the dimensions of the container were to comply with the ISO requirements. The total contract performance period was from 1 April 1973 thru 20 September 1973. Design discussions continued throughout the fabrication phase of the contract to insure that all design details met the requirements of the Air Force. An amendment was made to the contract during June of 1973 to provide another type of end closure for the building, a side entry system and several panels with windows. The cost for this modification was $20,000. The Department of the Army participated in the cost of this modification in the amount of $10,000. In September 1973, the first demonstration of the erection of three complete arches was held at the Lockheed Georgia Company for Air Force review and approval. During the first part of October, a full building erection demonstration was held at the Lockheed Georgia Company in Marietta Georgia, for the Army, Navy, Marines and Air Force personnel. The building was then dismantled, packaged and shipped to Tyndall AFB, Florida, for subsequent testing. The purpose of the evaluation program conducted by the Field Technology Directorate, AFCEC, was to ascertain the functional and operational capability of the shelter under adverse conditions and specific types of tests using strictly a military erection capability, such as would be found in actual field usage.

SECTION II

TEST FACILITY DESCRIPTION

1. Container. The container was 96 inches wide by 96 inches high and 117 3/4 inches long. The container base included four-way forklift tine-ways. The container had double doors in the front and the back and were used for loading and unloading the shelter components and used as an access into the shelter in the erected configuration. Four-Six-Three-L (463L) adaptors were to be provided with the container for adaptation to the M-51 configuration. All eight corners of the container were fitted with ISO corner fittings. The container had a payload of approximately 8500 pounds (Figure 1). The container was also used as a platform for the mounting of an erection winch that was used in the erection of the building.

2. A-Frame Gantry. An A-frame gantry was provided as the erection system for the other side of the shelter. The gantry had a telescoping mast to allow erection from two points on the arch. A winch was mounted on the gantry to facilitate the erection of the end walls and arch beams (Figure 2).

3. Base Channels. The base channels for the LOCARCH shelter were fabricated of aluminum channels that traverse the length of the building on each side. The base channels were pinned together using ball-lock pins. All the channel sections were interchangeable with the exception of the four end sections. A bracket was welded onto the channels spaced

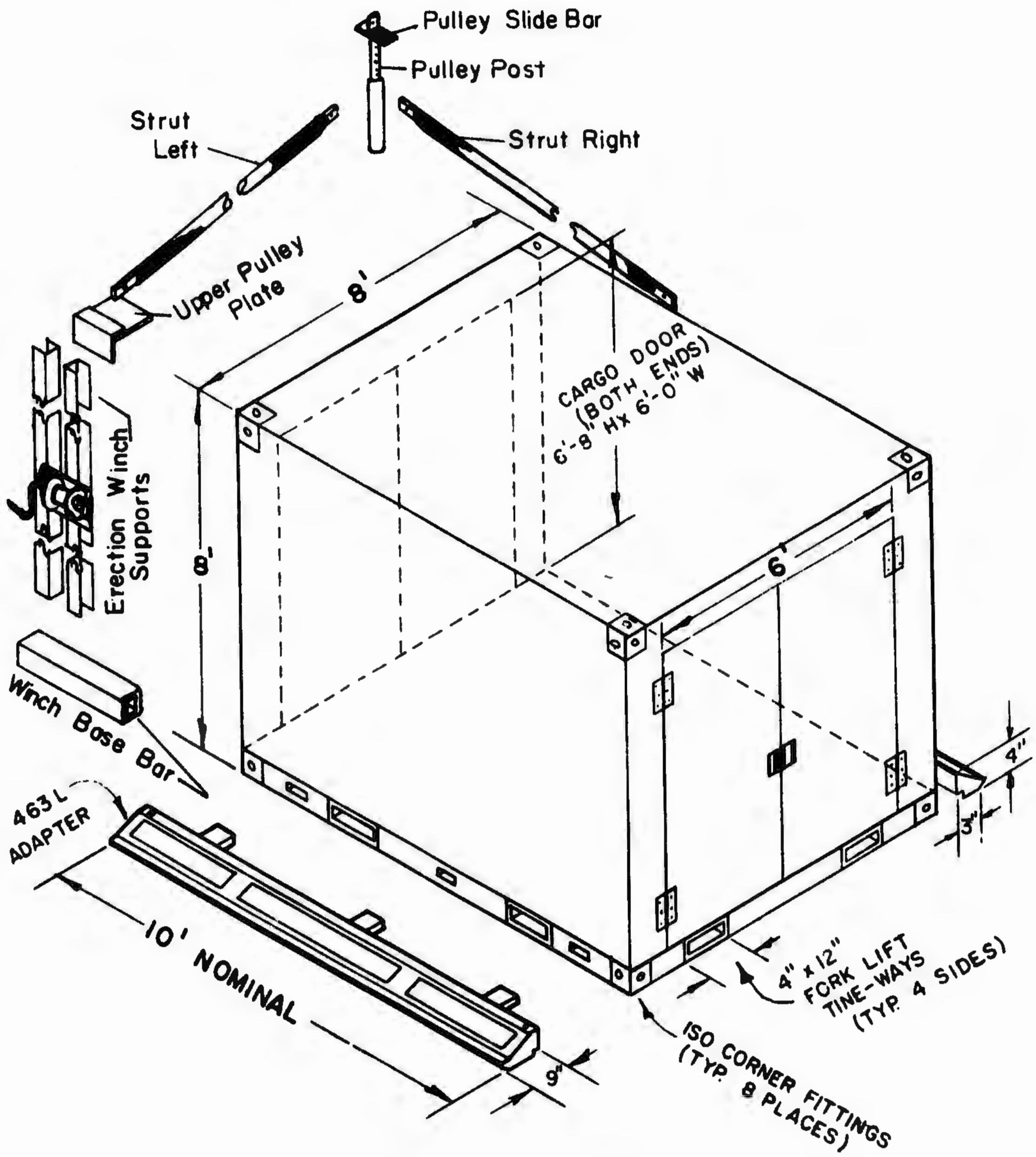


Figure 1 Shelter Container and Erection Winch

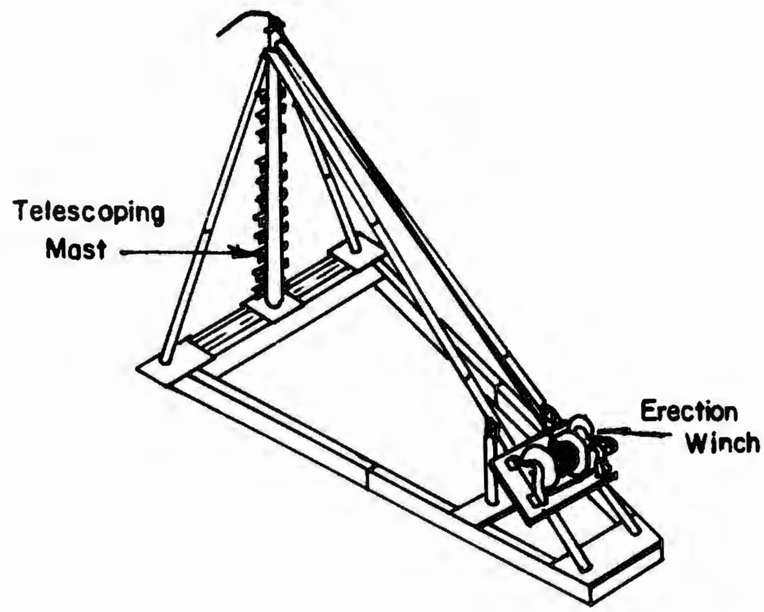


Figure 2 A-Frame Gantry System With Winch

eight feet, one-quarter inch, center to center. The arch beams were inserted into these brackets and secured with the locking pin. The arch beams pivot at this point from the horizontal to vertical postion (Figure 3).

4. Arch Beams. The arch beams were composed of three different types. The center beam had two bayonet-type plugs, one at each end. The standard arch beam had one bayonet plug and the base beam or ground beam had no bayonet plugs whatsoever. One end of the ground beam had an aluminum insert that allowed the base beams to be pinned into the base rail. The base beams were also equipped with a 1 1/2 inch downspout

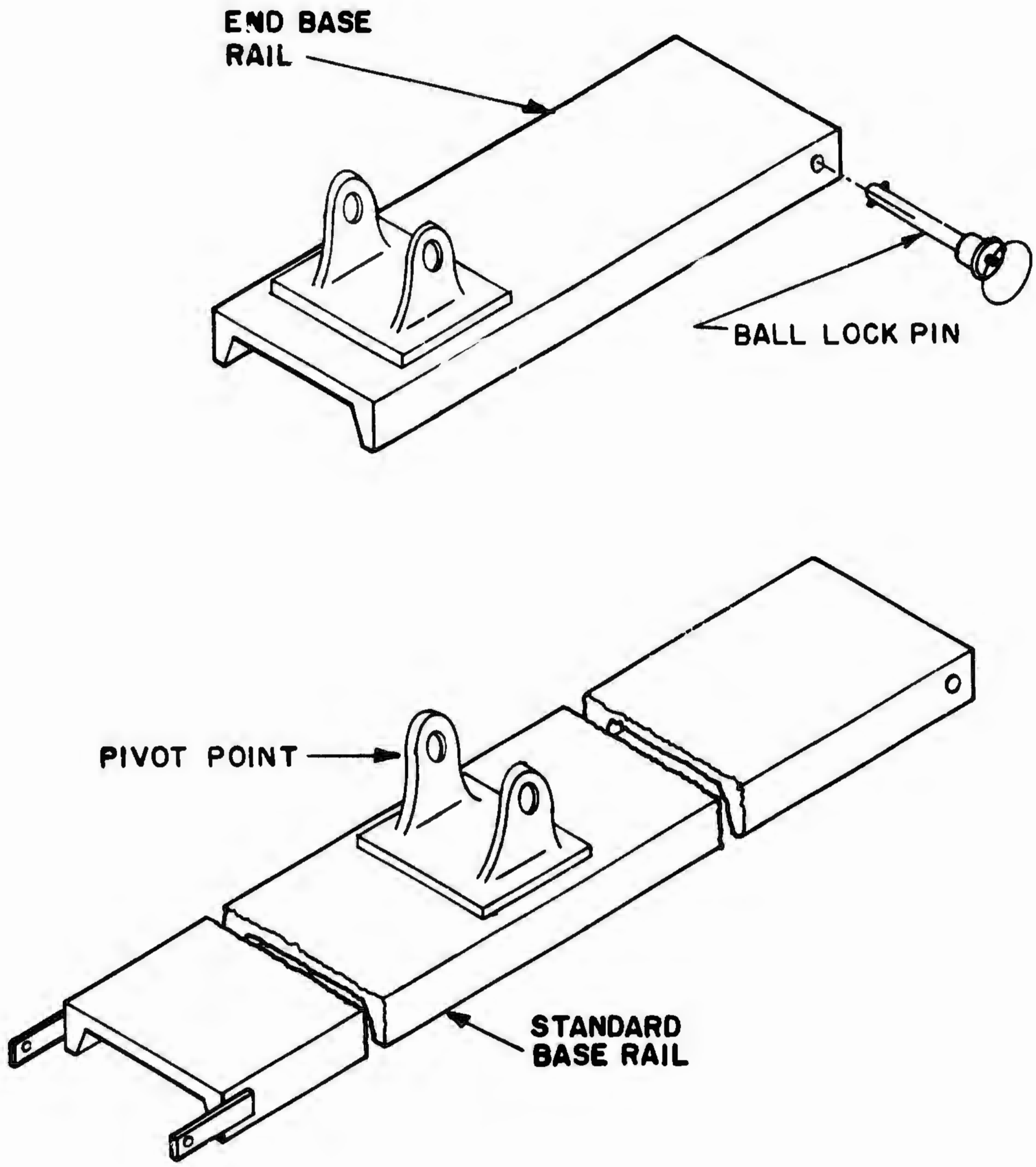


Figure 3 Base Channels

welded at the lower end near the pivot point (Figure 4). The different sections of the beams were fastened together using two pins that were inserted in the predrilled holes to secure the arch beam components.

5. Arch Panels. The panels were inserted between two arch beams and then pushed up over the arch with a panel installation winch system. The panels were fabricated with grooves or inserts in the four corners to allow the panel to attach to a track on the arch beam. Each panel was installed between the arch beams and pushed up over the top and down the other side. When the last panel in the arch was installed, a tensioning device was attached to the base rail to pull the locking members in the panel to a tension position, thereby providing the seal between the panels. Each panel was four by eight feet and one inch thick. The panels weigh approximately, 36 pounds each. The honeycomb core in the panels was a resinized paper using one inch thick 3/8 inch cell size, weighing 2.5 pounds per cubic foot. The honeycomb material was manufactured by Hexell. The face sheets over the honeycomb core were embossed aluminum .017 inches thick (Figure 5). These face sheets were glued over the honeycomb core, and the edge members were later attached. All panels throughout the whole shelter were interchangeable and could be used in any arch assembly. There were 23 panels that made up one complete arch.

6. Fabric End Wall. The fabric end wall was made up of extruded aluminum rectangular posts socketing into one another and pinned with locking pins to make up vertical supports of different heights to attach the fabric doors. These vertical posts were hung in a trolley track that was supported near the top of the arch. The vertical posts travel

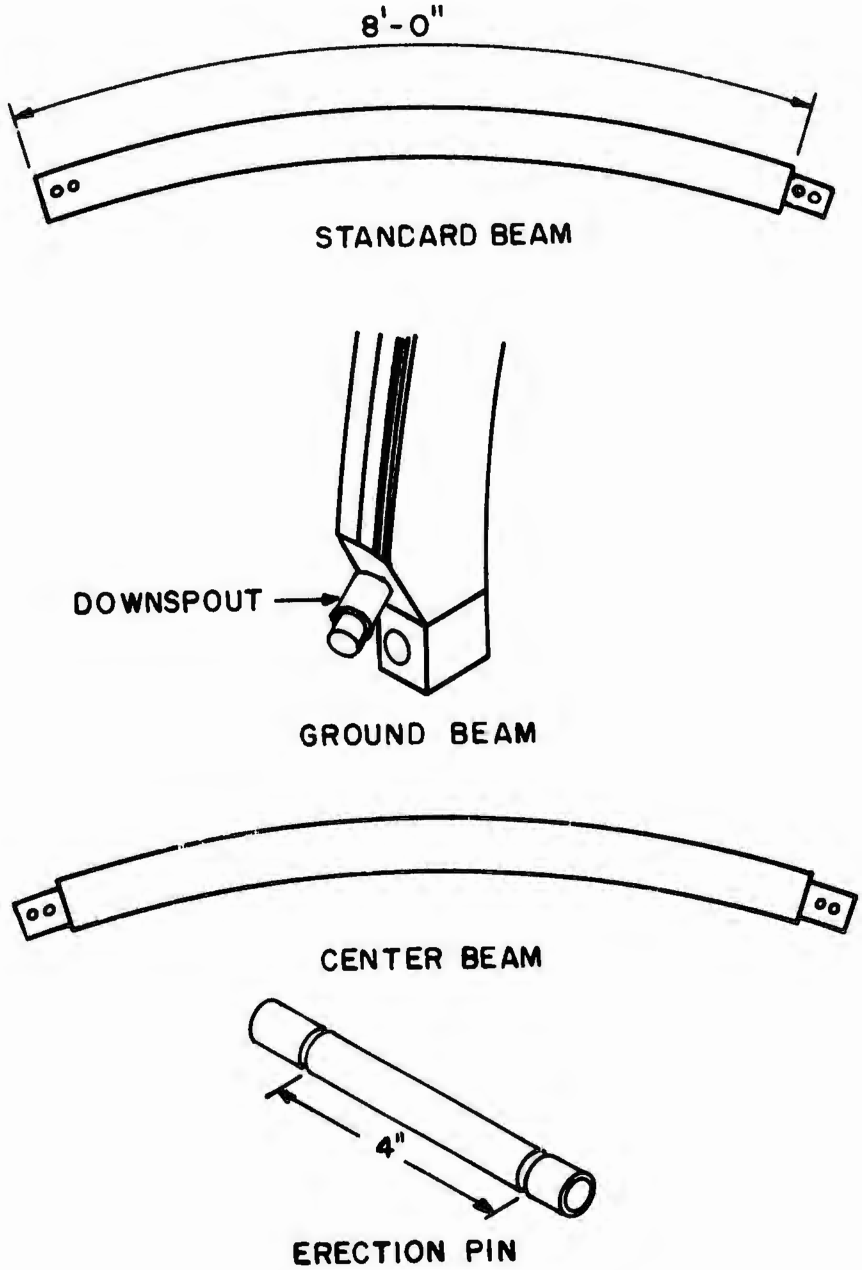


Figure 4 Three Types of Arch Beams

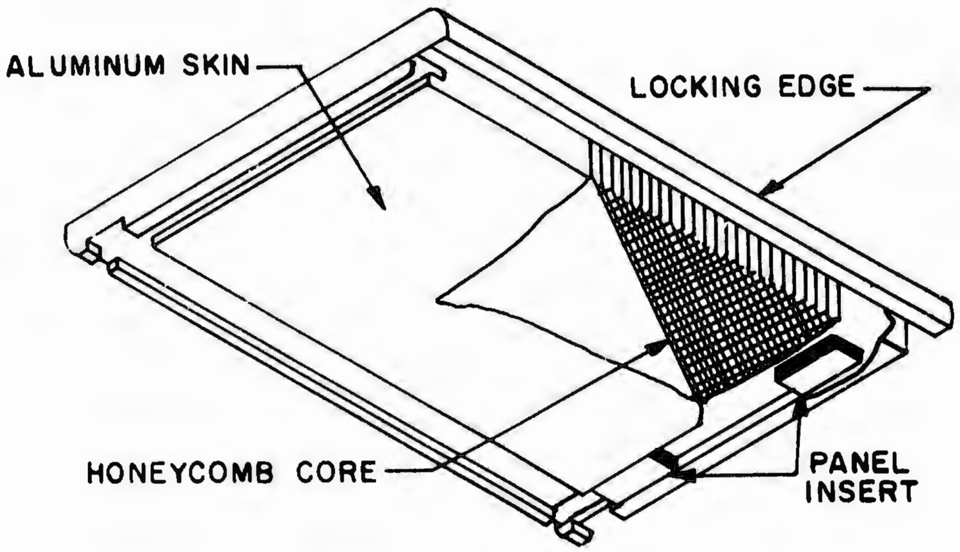


Figure 5 Typical Arch Panel

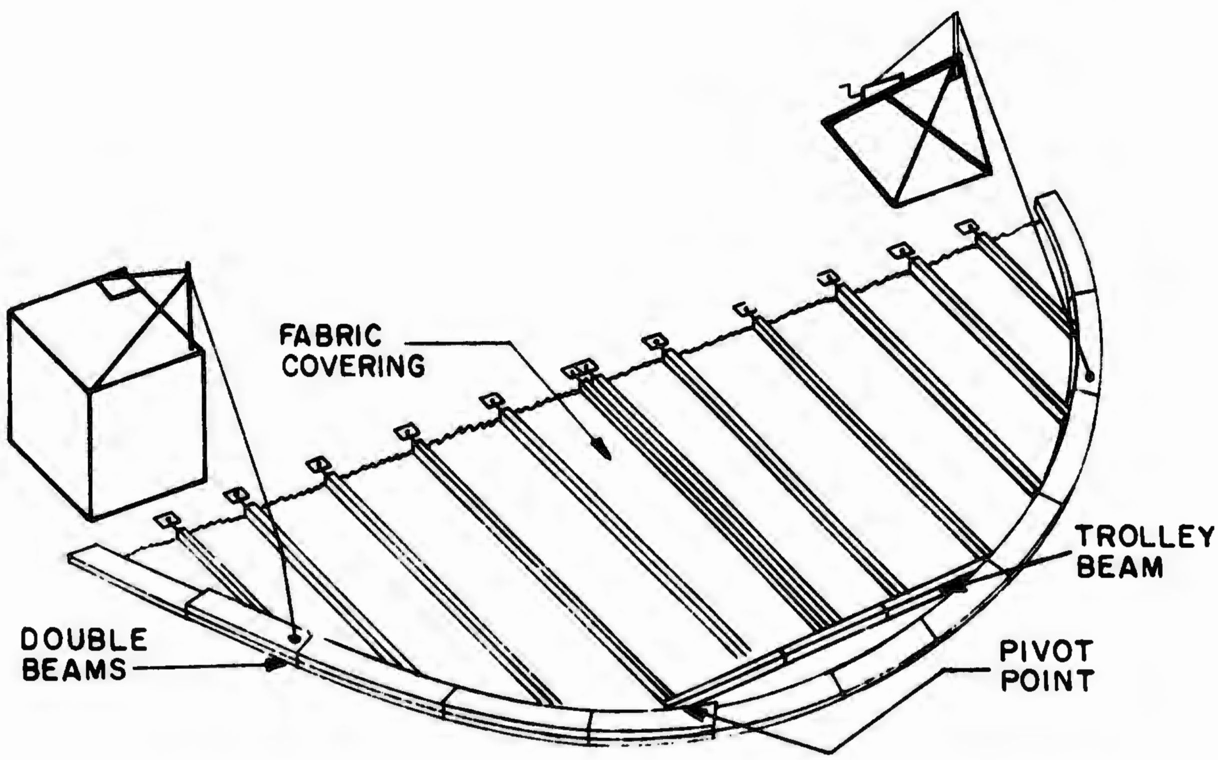


Figure 6 Fabric End Wall With Erection System

in the trolley track to a point where the trolley track ends. The fabric that covers the door is comprised of two similar sections. The fabric is secured around the vertical posts by a flap section fastened with gromments. The opening and closing for the door was accomplished with winches and cable to draw the door in the desired position. In the fully opened position, the vertical posts were pivoted on the trolley track to swing back and allow the full opening. The total weight of the door was approximately 3900 pounds. Because of this weight, the first arch beam had eight additional beam sections spliced to it to avoid failing the arch during the erection phase (Figure 6).

7. Metal End Wall. Extruded aluminum sections were socketed into one another and pinned with a locking pin and make up the vertical door posts. These posts travel in an overhead rail and operated in the same manner as a four-section accordion door. The panels were inserted between the door posts were made of corrugated siding. A piano hinge type arrangement was used to pin these panels to the vertical posts. The truck entry position was attained by moving half the door to a folded section and the other half remaining flat. In the full open position, all four sections of each side of the door were folded in an accordion fashion and secured with a retaining device (Figure 7). In the closed position, the doors utilize a telescoping pipe that extended from inside the vertical post and is locked into restraining plates that were anchored into the ground.

8. Side Entry Door. The side entry door system could be installed on any arch in the building system. It is comprised of a roof canopy

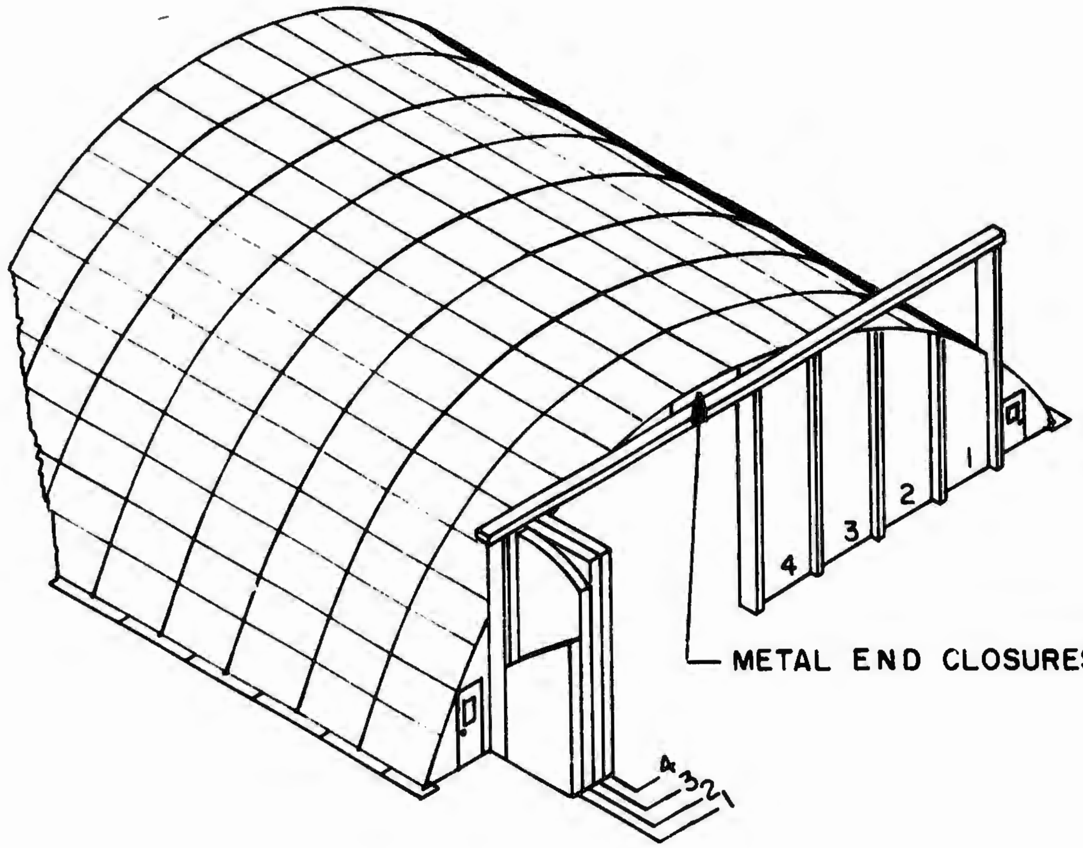


Figure 7 Metal End Wall and Doors

that locks into the arch panel and was pulled up on the arch and the side panels were fitted and locked into the rail on the arch beam. The door and wall panel tied into the side and roof panel and was attached to the base rail (Figure 8).

9. Ground Flashing. The ground flashing was a metal rail that hooked into the lower panel of the arch with a piece of fabric attached. This fabric was then anchored with sandbags to prevent the entry of water and blowing dust along the lower perimeter of the shelter.

10. Assembly and Erection Equipement. The arches were pulled from the horizontal to the vertical position by means of two 5-ton winches. As previously mentioned, one winch was installed on the end of the

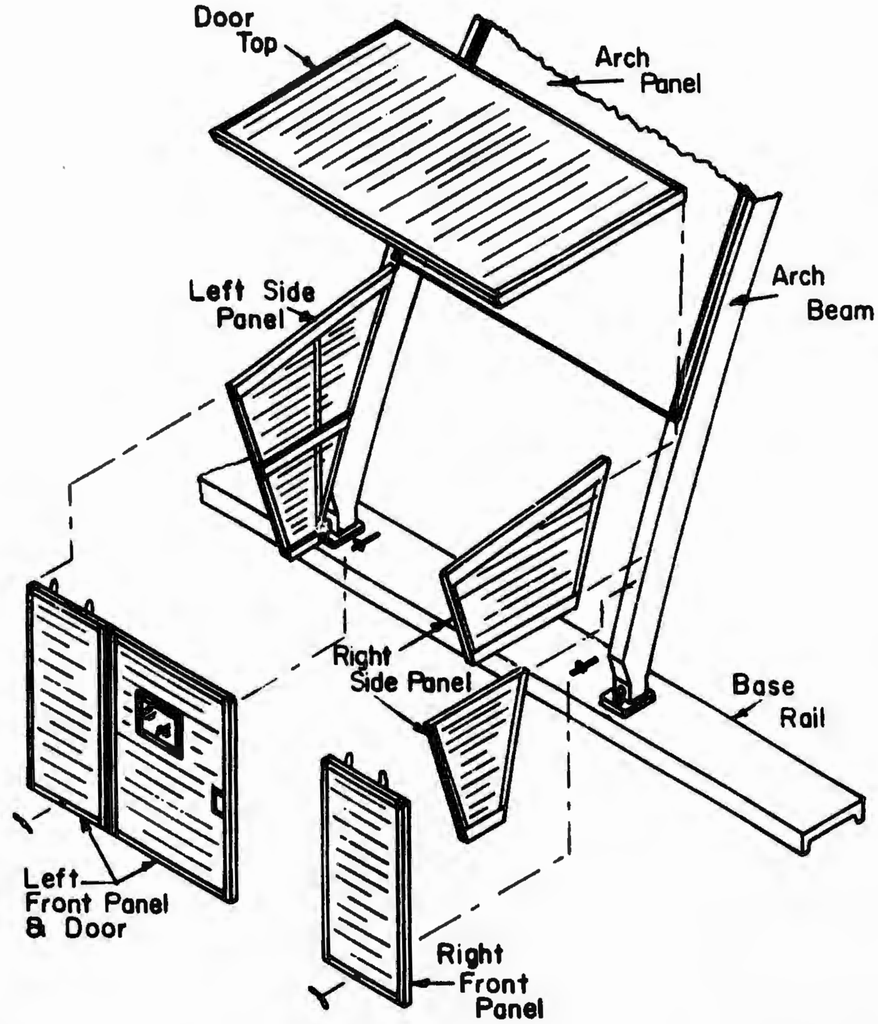


Figure 8 Side Entry Door System

container and the other was installed on the A-frame gantry. A cable was played out from these winches, attached to each arch beam or end wall and pulled into the vertical position. After the arches were in the vertical position, a panel winch was used to install the panels between the beams (Figure 9). The panel winch was a 2-ton, 2-speed winch that was mounted on a T-shaped aluminum beam system that fit between the arches. A cable was played out over pulleys that was attached to a hookbar that fit into the panel lock. The winch was operated until the panel moved up to the arch beams to the desired position. The bar was then disattached

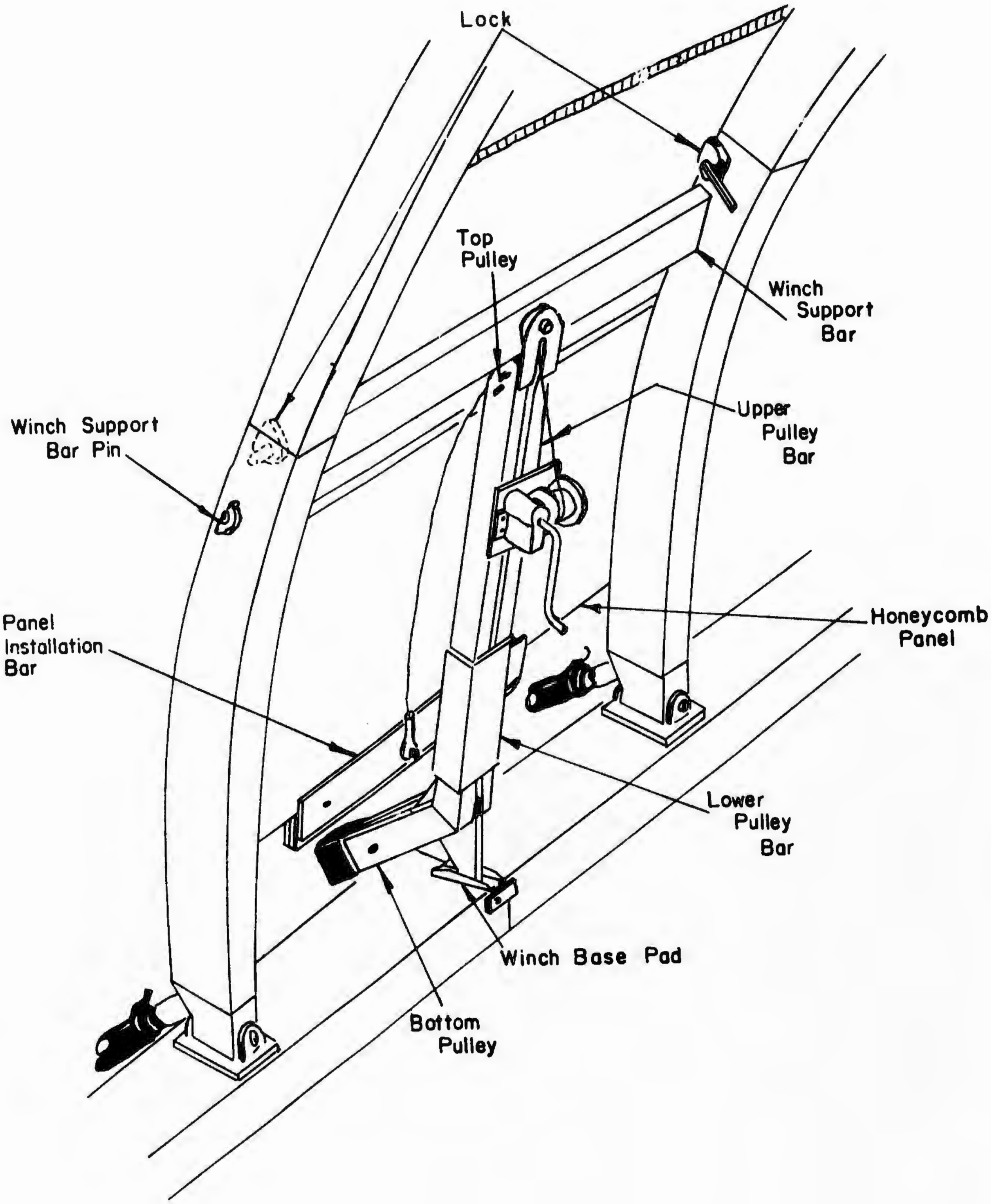


Figure 9 Panel Installation Winch Assembly

and another panel was layed on the arch beam tracks. The winch was turned and raised the panel to a specific point on the arch. Camlocks hold the panel from sliding back down the arch beams. Another panel was placed on the track, and engaged the locking edge member on the previous panel. The bar system attached to the cable was then put at the lower side of the panel being installed and raised to the position of the previous panel. This procedure is continued over the arch until all the panels have been installed.

11. Arch Restraint Bars. A T-shaped arch restraint bar was used when raising each arch. The top of the bar was eight feet long and it hooked over the cable pulling the arch to the vertical position. When the arch reaches the vertical position, the restraint bar prevents it from going over the center and falling onto the previous arch (Figure 10). The restraint bars were left in position until several panels were installed in the arch to prevent the arch from moving forward or backward.

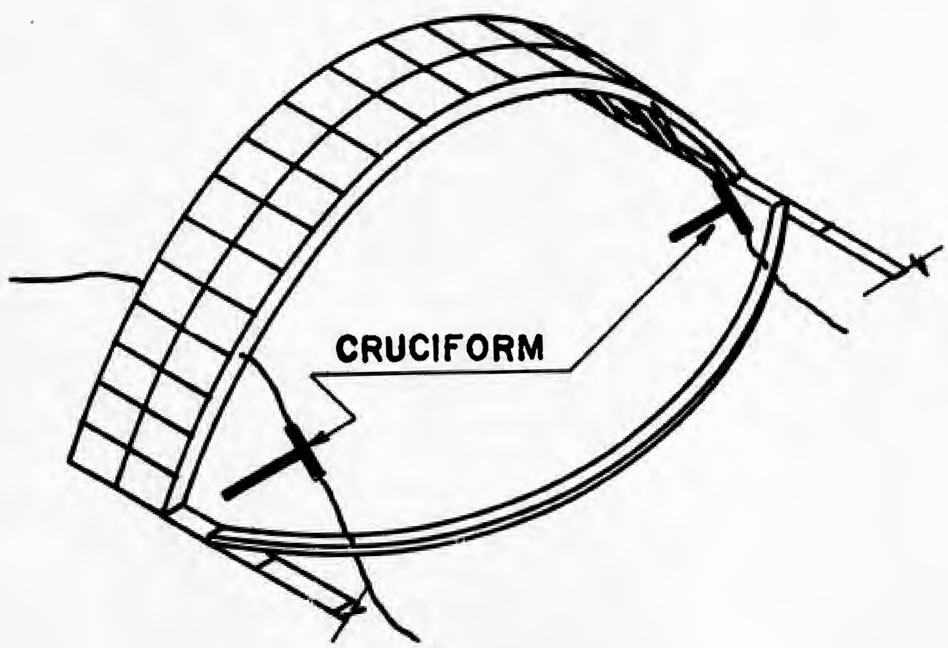


Figure 10 Arch Restraint Bar

SECTION III

LOCARCH ERECTION

The site that was chosen to erect the shelter was just east of the Field Technology facilities. The site was chosen because of the undulating sand that existed and could provide an extreme test as to the capability of the building to be erected over an 18-inch total difference in ground elevation for the length of the shelter. The contract did not provide for an anchoring system. It was initially envisioned to use the 4-inch arrowhead anchors that were in use in the Bare Base system. Because of the anticipated wind loading on the building and the number of arrowhead anchors it would take to secure the shelter in the uncompacted sandy soil, another anchoring system was devised as shown in Figure 11.

Figure 11 Anchor System Using Steel S'elter Liner Sections

A trench was dug around the outside perimeter of the shelter and the steel shelter liner sections were placed in the trench with cables. The trench was backfilled and compacted leaving the cables extended above ground. The cables were then wrapped around the base rail and restrained the building movement if it was subject to extreme wind loads when erected. After the backfilling over the anchor systems and the area was brought to the desired elevations, the building layout and assembly was initiated. Figure 12 is a picture of the building components as they were received on pallets from Lockheed. The area where the shelter was erected, was just left of the components.

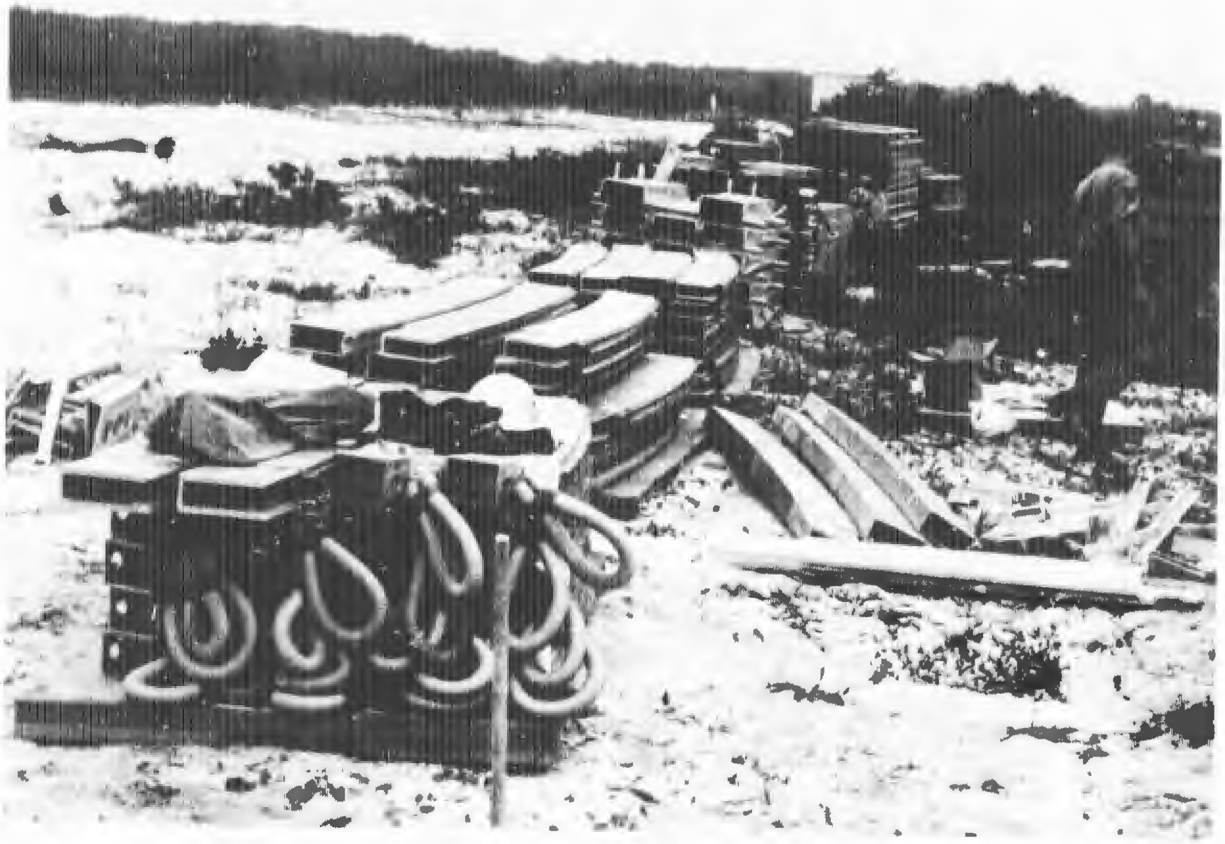


Figure 12 Palleted Shelter Components Prior to Erection

Figure 13 shows the arch panels as they were received from the contractor. Some minor damage was experienced during shipment as indicated on the top panel of the pallet. This was easily corrected by means of a screwdriver that was inserted in the aluminum extrusion and the aluminum extrusion bent back to shape.

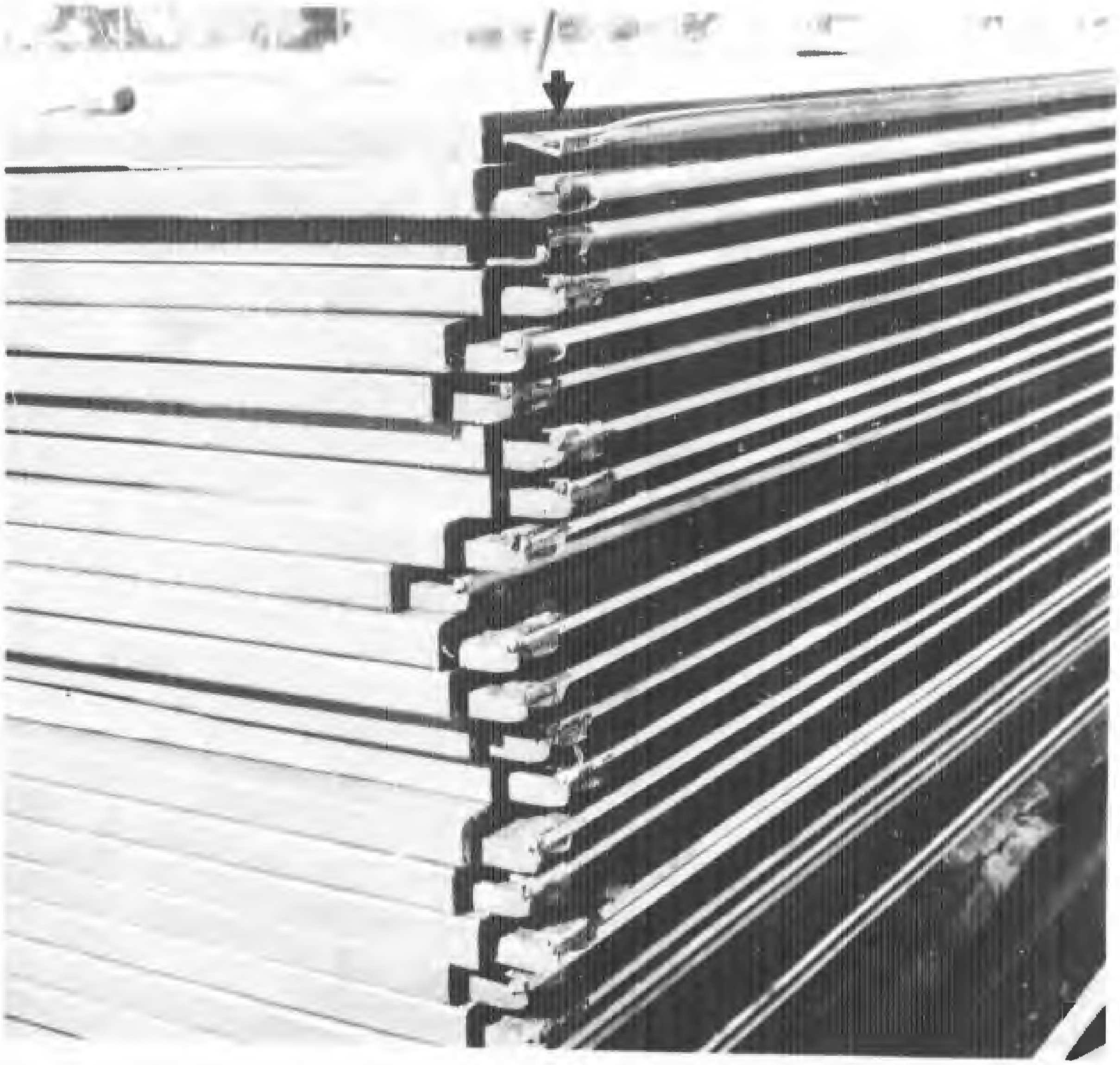


Figure 13 Arch Panels as Received From the Contractor

The first work effort that was undertaken was the assembly of the A-frame gantry. All the pieces were marked by the contractor for the assembly procedure. Some difficulty was experienced at this point in putting the A-frame together, in that the holes that were predrilled for the components provided a very snug fit. Also, bolts and nuts were required for the assembly. This problem could have been overcome by fabricating interchangeable components for the A-frame and providing lock-pins to fasten the sections together instead of the bolts and nuts.

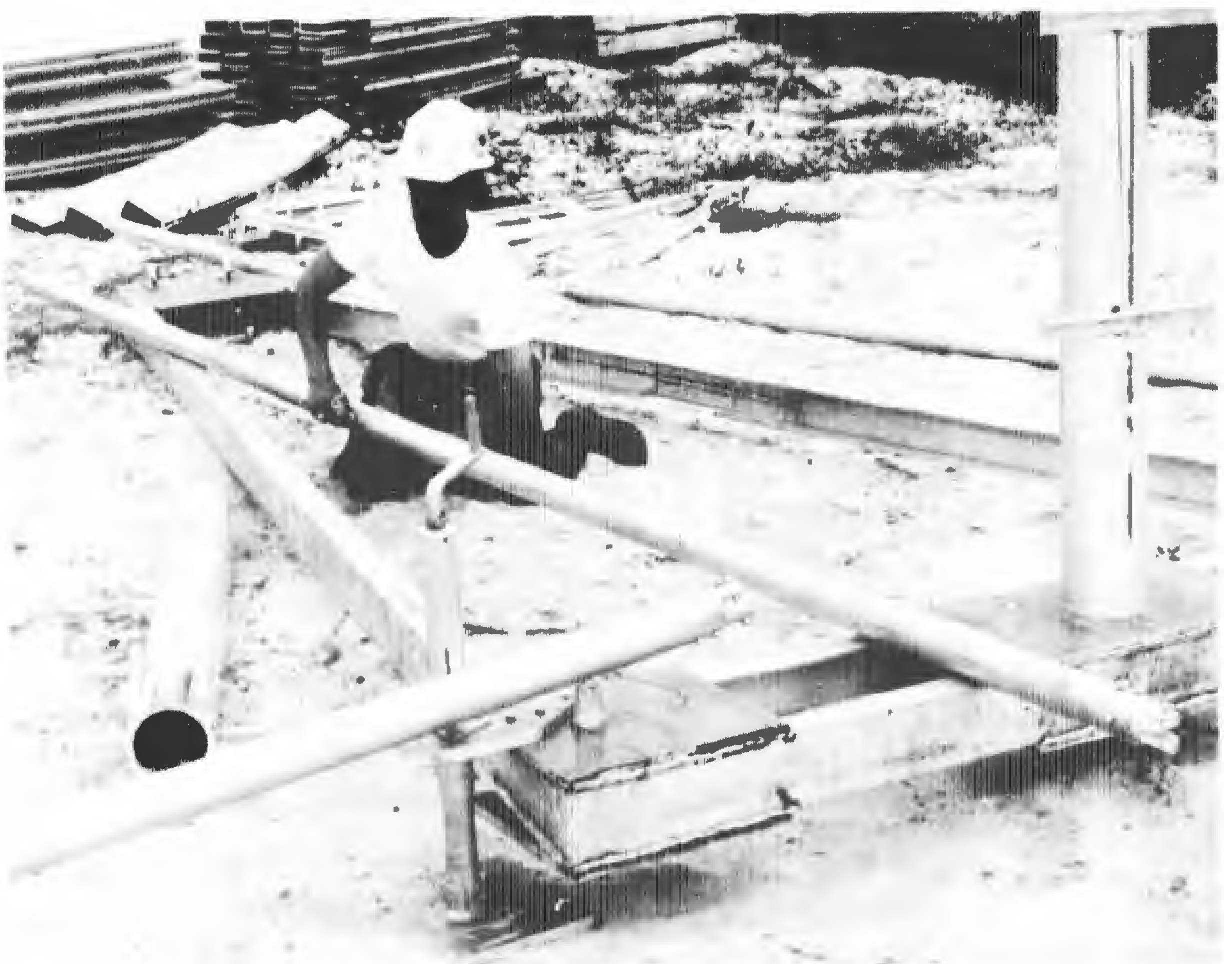


Figure 14 A-Frame Assembly

Assembly of the erection winch system on the container was the next endeavor undertaken. Figure 15 shows the leveling system that was used to level the container. It worked very well and provided a good platform for the container to rest, even though the surface was quite uneven. The container and the A-frame were attached to the anchor cables that had previously been installed.

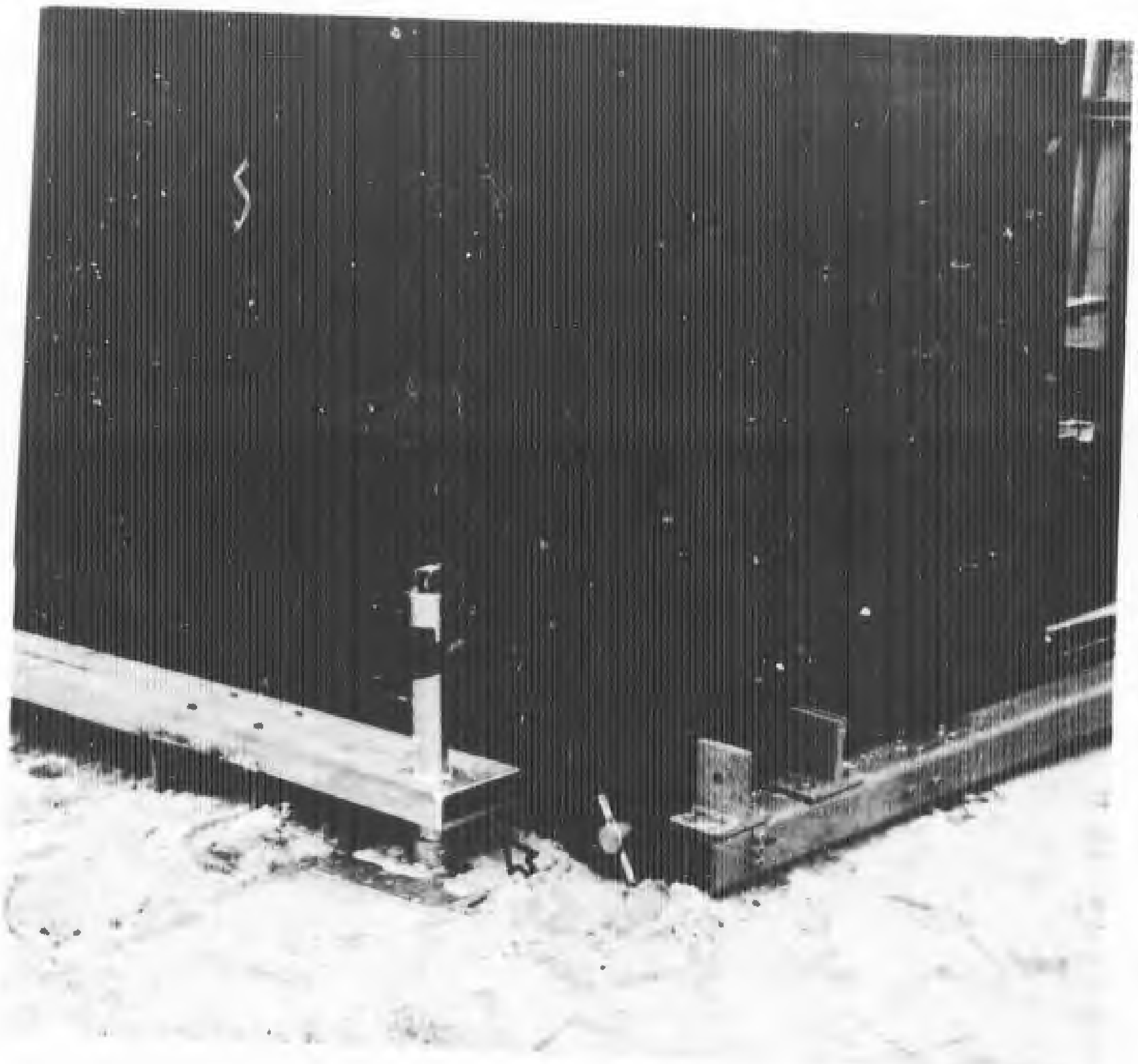


Figure 15 Container Leveling System

The components of the container winch system were attached to the container to prepare for the arch assembly and erection (Figure 16). The parts were pre-marked for identification and fit together without any difficulty.

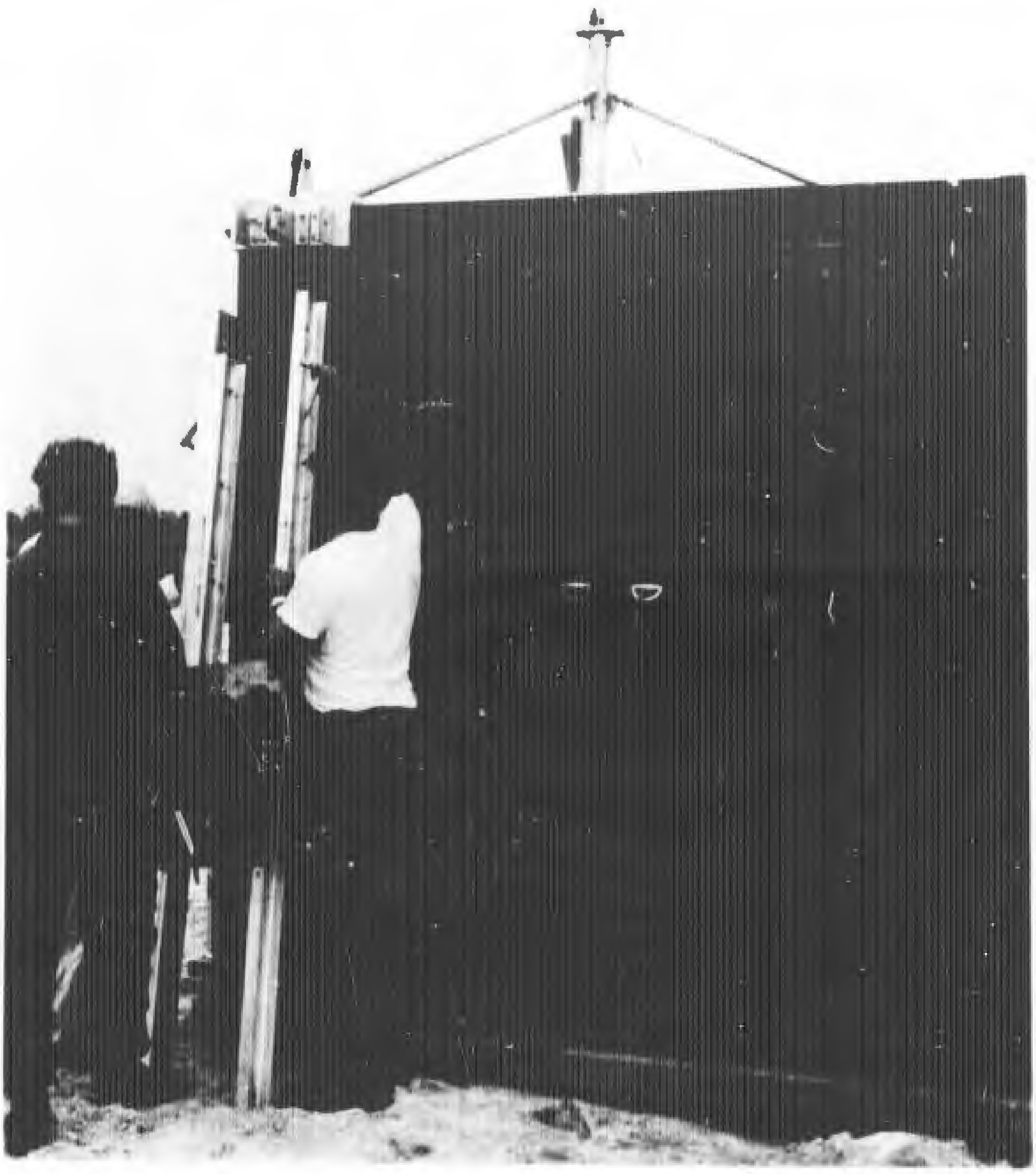


Figure 16 Mounting the Erection Winch on the Container

The exact location of the base channel was determined by use of the cable layout system supplied with the shelter (Figure 17). The size of the cable was 1/4 inch and provided no structural tie between the rails. Holes were pre-drilled in the base channels for the cable pins to be inserted.

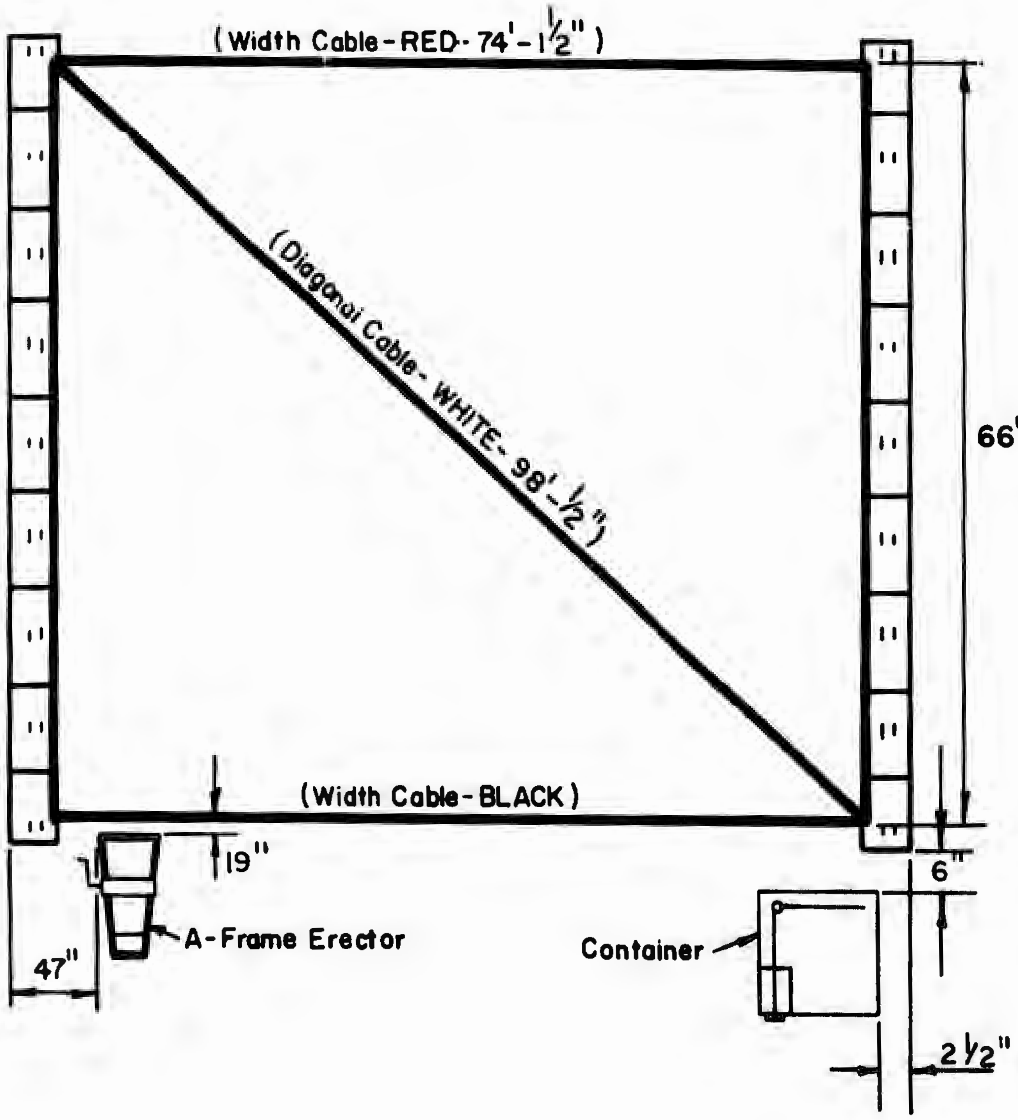


Figure 17 Base Channel Location Cable System

The rails were tied together with the ball lock pins for the full length of the shelter. The assembly of the base rails was very simple and accomplished in a very short period of time. While the assembly of the erection mechanisms was being prepared and the base rails positioned, the first arch beam was laid out on the ground (Figure 18). It was assembled first by starting at both sides and coming toward the

Figure 18 First Arch Beam Being Assembled

center, but it was discovered that it was difficult to install the center beam with both ends pinned into the base rail. The procedure was later changed by assembling the arch beams from left to right. When the procedure was changed, the arch beams went together much faster; but the use of a prybar was required in some instances to push the arch beam into the bracket on the base rail. The assembly of the fabric door took place while the arch beams for the remainder of the building were laid out on the ground prior to assembly. All the pieces of the fabric door were well marked and did not cause any problem during the assembly. The Lockheed representative on site did provide assistance when required because the draft erection manual provided by Lockheed was not specific enough in certain areas. After the door was assembled, the fabric material was attached to the vertical posts. There was a great number of grommets on the fabric, each requiring hand fastening (Figure 19). One of the stipulations in the statement of work in the contract, required that the building could be completely assembled by personnel in an arctic climate wearing mittens. The small size and number of the grommets for the fabric door would make this task difficult for personnel wearing mittens. No major problems with the grommets were encountered at the test site. The assembly of the arch beam and fabric door took approximately 14 man-hours. (All man-hours relating to the first assembly and erection of the building are shown in Table 2, page 45.)

Figure 19 Grommets Being Secured Around Vertical Beams

The second arch beam was pinned together with some difficulty being experienced inserting the pins between arch beams segments. Upon completion, all was ready for the raising of the fabric door and end wall (Figure 20). Two men manned each of the 5-ton winches and began pulling the end wall to the vertical position. The point on the arch where the cable was attached from the top of the pulleys caused an initial reaction of the whole arch and door assembly to try and come forward toward the winches. This caused the extreme ends of the base rails to begin raising from the ground (Figure 21). After the door was pulled about one-third of the way to the vertical position, the base rails

Figure 20 Fabric Door Assembled on the Ground

Figure 21 Fabric Door Being Raised to Vertical Position

went back to ground level, and the raising of the door continued. As the door came to the proper position, it was tied in place at the top of the A-frame and the container erector to hold it in the vertical position. The winch cable was disconnected from the end wall and pulled through the beam and attached to the second arch beam. Raising of the second arch beam took about one-tenth of the lapse time required for the raising of the fabric door. The arch beam itself was very light and was easily brought into the vertical position by one man on each winch. The arch restraint bars were put into position to hold the second arch in place while the panel insertion was initiated between the arches. On the day that the erection took place, 15 knot winds, gusting to 25 knots were experienced. This caused extreme difficulty in installing the panels between the first arch with the fabric door and the second arch beam. Initially, the door was left in the closed position, and the wind caught the fabric causing a sail effect and kept moving the end wall in relation to the second arch beam. The installation of the panels became very difficult after the third or fourth panel because of the wind effect on the beams. When 15 panels were installed between the arch beams, the wind was no longer a problem. Also, the fabric door was pulled open to the truck entry position to reduce the sail effect on the door (Figures 22 and 23). As the installation of the panels between the first and second arch beams proceeded, the remainder of the arch beams were assembled and the frame work for the metal end wall was initially laid out. (Figure 24, note the slot cut in the arch beams.) There is one slot per arch beam. The purpose of this slot is to collect rain water as

Figure 22 Fabric End Wall in Vertical Position

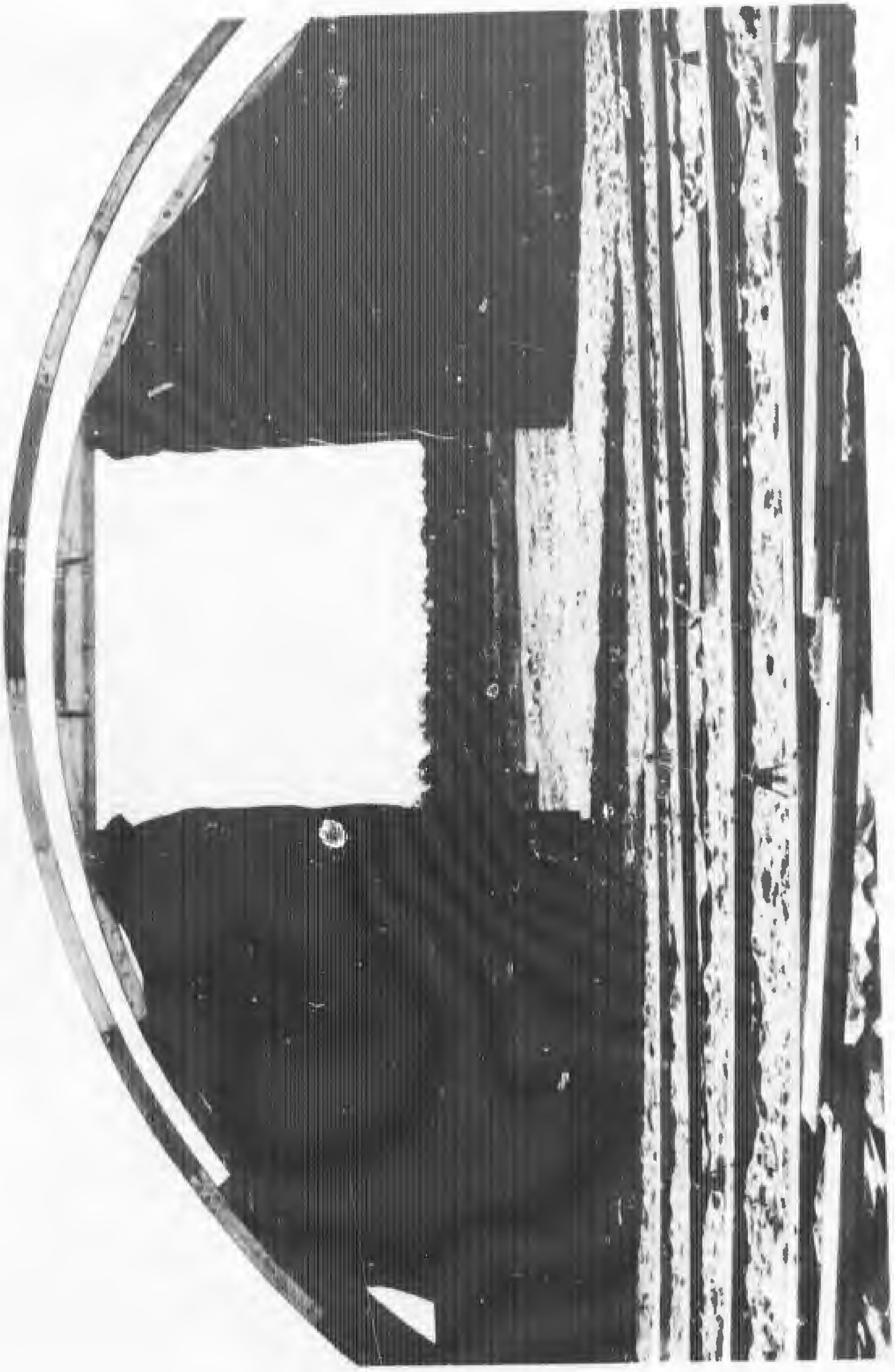


Figure 23 Fabric Door in Truck Entry Position with Arch Beams in the Foreground

it accumulates over the arch and carry it down through the arch beam out the drain at the bottom. This particular point will be discussed in Section IV, under the topic of Water and Wind Test (Page 79).

Figure 24 Arch Beam Assembly and Layout of Metal Door Frame Work

Figure 25 shows one man carrying one of the 4 foot by 8 foot panels. The 36 pound weight of these panels made them easy for the erection personnel to handle and caused no difficulty in moving panels to the arches for insertion.

Figure 25 Erection Personnel Carrying Arch Panel

Figure 26 is the T-bar and panel winch installed between the first and second arch and the second panel being raised between the beams. The base of the T-bar was attached on the base rail, the winch was operated to pull the panel upward on the beams. The panel shown in the photograph is approximately two thirds installed.

Figure 26 Panels Being Installed With Panel Winch

Figure 27 shows the third panel being installed between the arches with the grab bar on the bottom of the panel. Note also in Figure 27, that the cable for the arch beam winch system on the container is slack while the panels are being installed between the arches. The

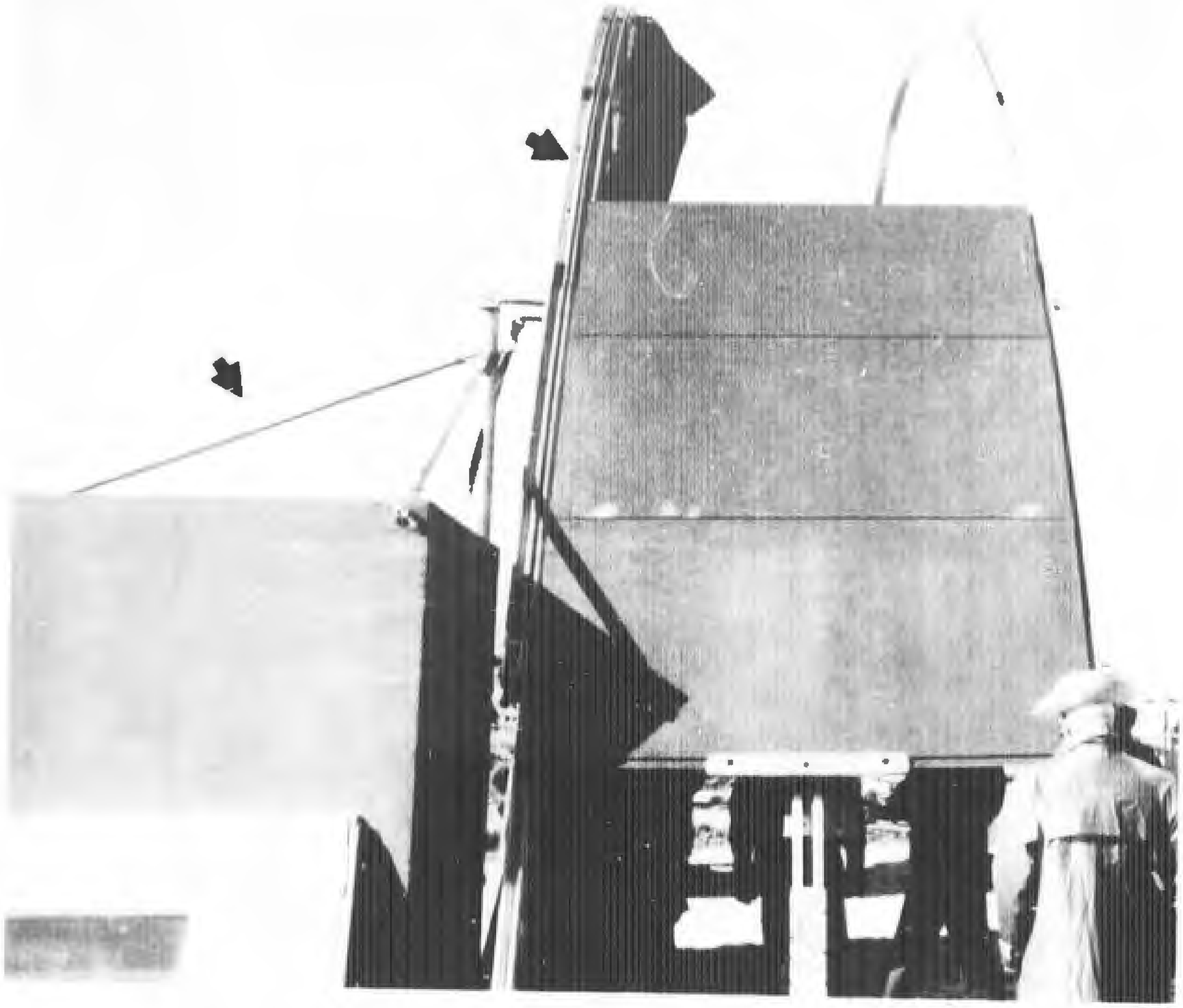


Figure 27 Third Arch Panel During Installation Taken From Outside the Shelter

picture also shows the double arch beams used to reinforce the arch for the fabric door. All the other archs were single beams throughout the rest of the building.

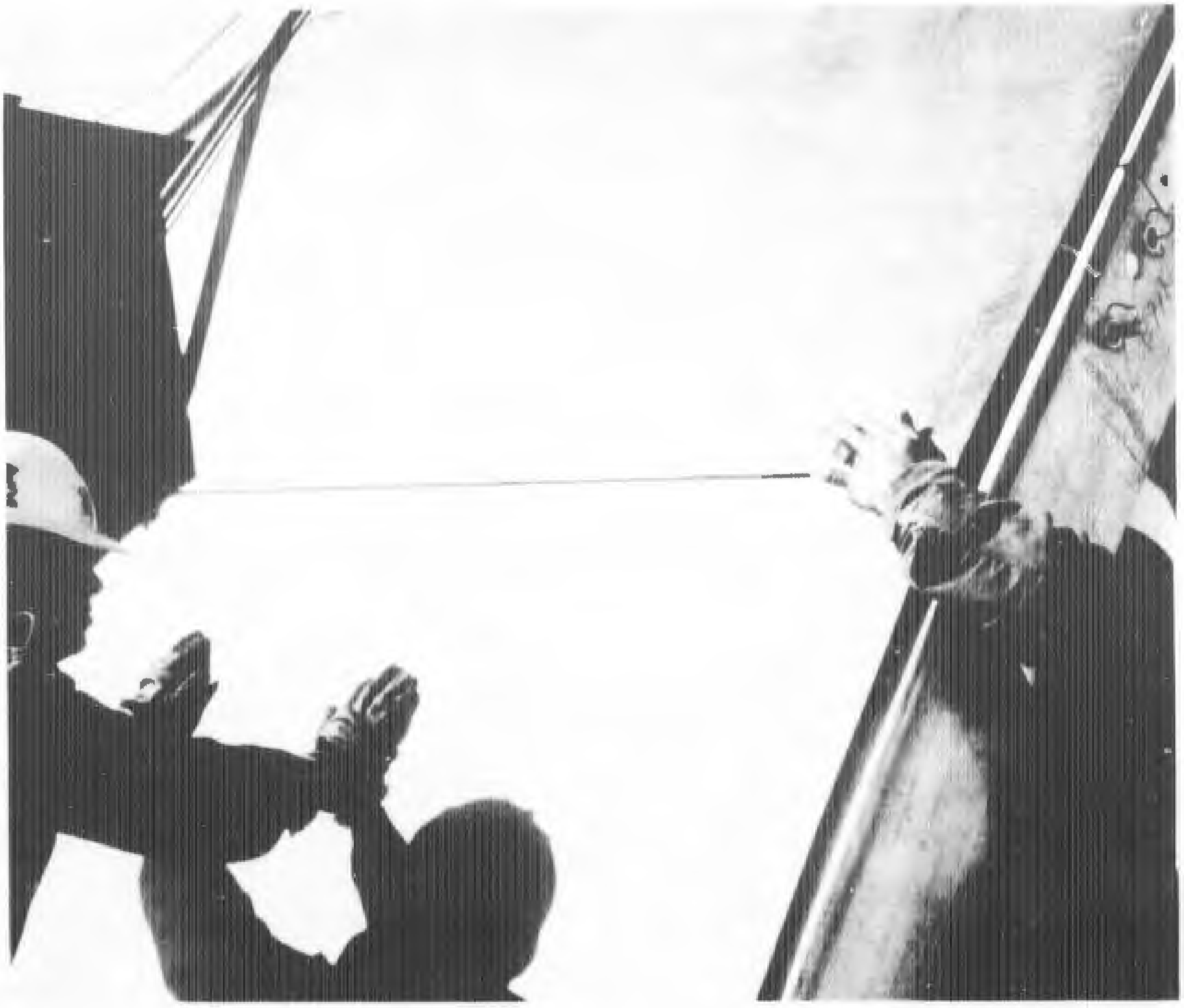


Figure 28 Pressure Being Applied to Panel Corners to Start on Arch Beam Track

In Figure 28, the personnel were putting pressure on the panel at the point where it was installed in the track. If pressure was not initially maintained at this point, the winching of the panel on the track would sometimes miss the insert in the corner of the panel. It then became necessary to reverse the cable and pull the preceding panel down to where the next panel could again be locked at the edge member and set on the track.

The panel installation continued on the first arch until all panels were in place. They were all installed by physically turning the panel installation winch. This process took approximately 13 1/2 man-hours. After all the panels were in place, the panel ground skirt was installed and the tensioners were secured to the base rail and the panels were tensioned in the arch (Figure 29).

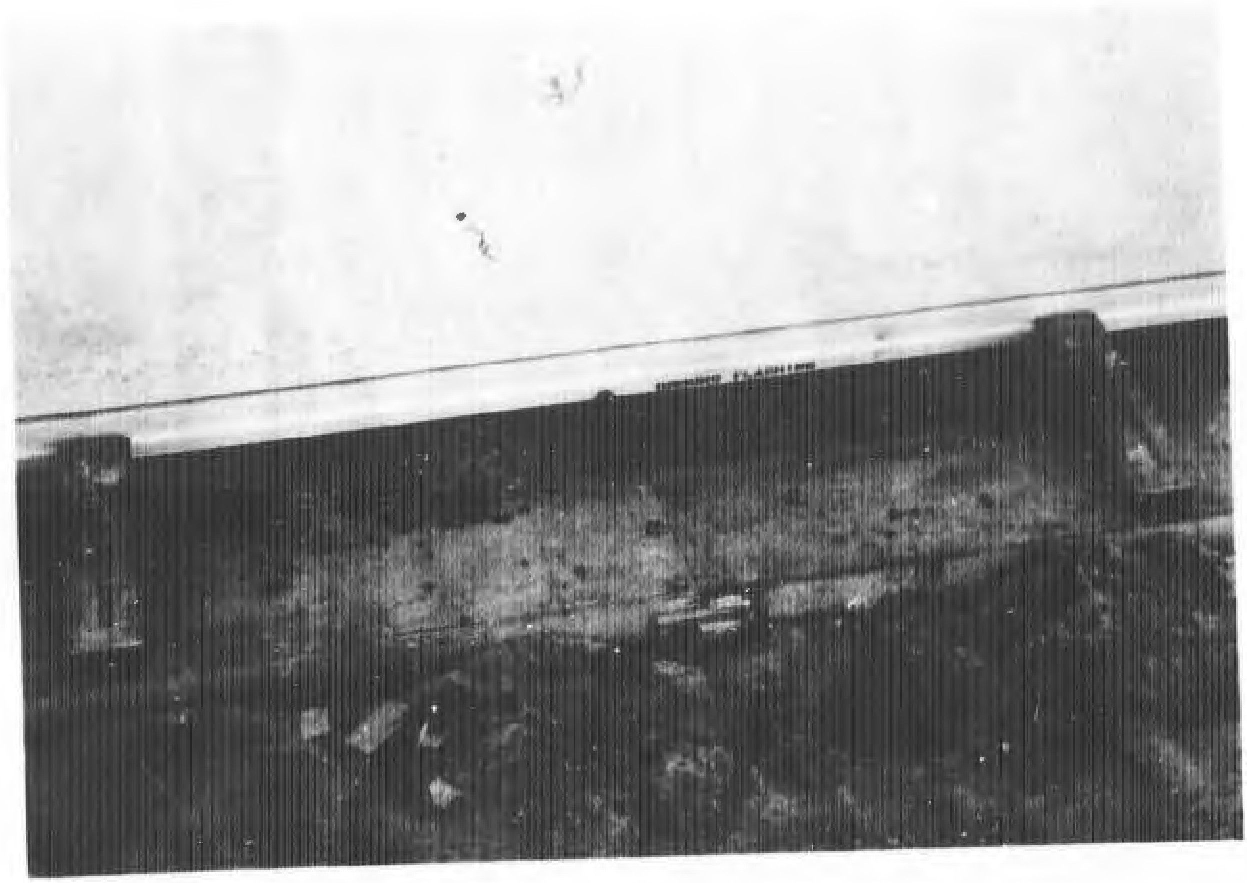


Figure 29 Panel Tensioners in Place on First Arch

It became apparent as the first arch was finished that the base rails were moving apart, due primarily to the weight of the fabric door and the force exerted on the arches as the panels were being pushed over the top and down the other side. As stated previously, the anchoring of the base rail was accomplished prior to the building erection and all the cables were on the outside of the building. Had some anchoring devices been placed on the inside of the building to prevent the movement, the problem may have been alleviated. As the base rails spread apart, the arches were elongated causing additional difficulty in installing the panels.

As the time passed, the blowing sand had accumulated on the arch beams tracks because of the lubricant that was on the tracks when the shelter components were received from Lockheed. It was determined that this buildup of sand restricted the sliding of the panels on the arch beams and made the panel installation much more difficult. Before the third arch beam was raised and all subsequent beams, the tracks on the arch beams were cleaned with a rag.

The third arch beam was then raised to the vertical position and the panels were subsequently installed. Time was reduced by 50 per cent to install the panels, partially because the track was cleaned and a 3/4 inch drill motor was used to turn the panel installation winch rather than strictly manpower. The drill worked well with only minor overheating. During the installation of the panels between the third and fourth arch beams, a manual panel insertion was attempted rather than using the panel winch. Figure 30 shows two personnel were able to

install the second panel by hand. Twelve panels were installed by hand on the third arch using five personnel pushing the panel in place. The remainder of the panels were installed, again using the drill motor.

Figure 30 Installing Panel Mannually

Table I indicates the number of panels that were installed by hand in each of the arches.

TABLE I

Panels Installed Mannually

Arch No.	Number of Panels
3	12
4	8
5	14
6	11
7	9
8	4

The side entry was installed between the fourth and fifth arches. The panel winch had to be taken to the opposite side of the building for the installation of the side entry. This was necessary because the roof of the entry way was required to be attached to the 22nd panel and then all the panels on the arch were pulled back to allow for the installation of the lower part of the entry way (Figures 31 and 32). After the roof and side walls were installed on the track, the door enclosure panel was bolted to the track and base rail. The side entry system was quite easy to install and worked exceptionally well. In Figure 33, the side entry was installed in place and preparation is being made to pick up the sixth arch beam.

Figure 31 First Step to Install Side Entry System

Figure 32 Installing Lower Panels on Side Entry

Figure 33 Cable Being Attached to Sixth Arch ᵔ am Side Entry System in Place

During the erection of the fourth, fifth, sixth and seventh arches, the wind subsided considerably; and, with the hand installation and drill motor procedure, the erection and assembly of these arches went quite well. Experience in erecting the arches was also a contributing factor for the better time.

Before the ninth arch could be raised, the metal end wall door had to be assembled since it was to be raised to the vertical position in conjunction with the arch. The door consisted of a great number of pieces, all of which would fit only in one particular place (Figure 34). The vertical beams caused no difficulty in assembly. The corrugated panels that fit between the beams were somewhat difficult to install (Figure 35). The method of attaching the metal panels to the vertical beam was by means of a piano hinge, half on the beam and half on the panel. A long pin was required to be inserted all the way through this hinge joint before succeeding panels could be installed. Trying to keep the panel in a perfectly horizontal position to match the hinges on the beam proved to be very difficult and the pin had to be driven in with a hammer an inch or so at a time. The assembly of the door took approximately 50 man-hours and was the most time consuming effort on the erection of the building. After the completed assembly, the raising of the metal door commenced. As the winches were turned, the base rail began lifting from the ground (Figure 36). As the winches continued to turn, the base rail came up approximately 18 inches. The door was lowered to the ground and a more secure anchor was placed parallel to the axis of the base rail. After the anchors were installed, the door was raised to the vertical

Figure 34 Metal Door Components Before Assembly

Figure 35 Installing Panels Between Vertical Supports, Metal Door

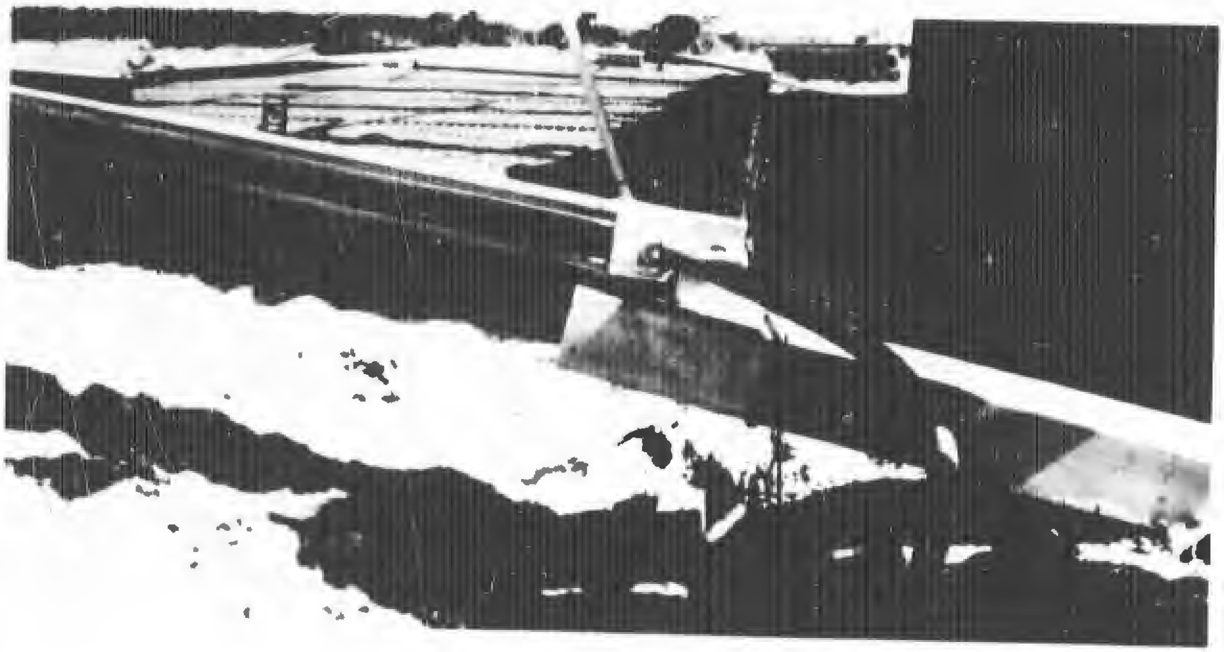


Figure 36 Base Channel Raising During Metal Door Erection

position with no problems (Figure 37). The last row of panels were then installed between the eighth and ninth arch beams. Only four panels were able to be installed by hand and then the drill motor was used. The last four panels were extremely difficult to install and the work had to be stopped after each of the panels were installed to cool the motor.

Figure 37 Vertical End Wall Being Pulled to Vertical Position

The total erection time for the building was 173.5 manhours. This was considerably more than the contractor's erection time due primarily

TABLE II

Erection Time

TASK		TIME (M/H)
1.	Locate Base Rail with Layout Cable	0.5
2.	Assemble A-Frame Gantry and Install Winch System on Container	6.0
3.	Assemble Base Rails	2.0
4.	Install Fabric Door Anchor Plates	10.0
5.	Assemble First Arch Beam and Fabric Door	14.0
6.	Raise First Arch Beam and Fabric Door	2.5
7.	Assemble Second Arch Beam	2.0
8.	Raise Second Arch Beam	0.3
9.	Preposition Panels Along Side of Shelter	2.0
10.	Install Panel Between 1st and 2nd Arch Beams (Manual Crank)	13.3
11.	Assemble 3rd Arch Beam	1.3
	4th Arch Beam	1.5
	5th Arch Beam	1.0
	6th Arch Beam	1.0
	7th Arch Beam	1.0
	8th Arch Beam	1.0
12.	Raise Third Arch Beam, Clean Grooves and Align Base Rail	2.0
13.	Raise Arch Beam and Install Panels between:	
	2nd & 3rd Arch	6.0
	3rd & 4th Arch	5.3
	4th & 5th Arch	6.0

(Table II, Continued)

TASK		TIME (M/H)
	5th & 6th Arch	4.0
	6th & 7th Arch	4.0
	7th & 8th Arch	4.0
14. Install Side Entry Door		2.0
15. Assemble 9th Arch and Metal Door		49.0
16. Install Track For Metal Door		2.5
17. Raise 9th Arch and Metal Doors		7.5
18. Install Panels Between 8th and 9th Arch		7.5
19. Install Personnel Door (Metal Door)		5.3
20. Install Personnel Doors (Fabric Door)		7.0
21. Install Opening Mechanism (Fabric Door)		8.0
TOTAL:		173.5

to inexperience of the personnel in working with the building components. The individuals who worked on the erection had never seen any literature on the building and it was a first time effort on their part. Also, the first edition of the erection manual was vague and not sufficiently definitive to clearly portray the steps to be taken during the erection. The Lockheed representative who assisted during the erection only offered advice when the erection instruction could not be understood or difficulty arose during the building assembly. As shown in Table II, the more experience the personnel had with the raising of the arch beams and installation of the panels, the better they did. Four man-hours to install the arch between the beams actually took about 45 minutes lapse time. The drill motor provided great assistance during the erection as did the hand installation of the panels. Cleaning the tracks of the arch beam reduced the friction effect of the sand that was constantly blowing in the area. The panel installation winch did not perform satisfactorily during the erection. On the second row of panels, the drum keeper on the winch broke, which allowed the durm to slide on the shaft, thus causing wear on the drum notches. The keeper appeared to be made out of brass and could not stand the pressing action of the drum. The keeper was replaced with a piece of 7x1x1/2 inch steel plate. After this modification was made, the operation was able to continue. Later testing on the building required several modifications to the winch to keep it on operation. Overall, the winch was not heavy enough to withstand the amount of pressure that it was required to withstand during multiple assemblies and disassemblies. The pins that held the

arch beams together sometimes were very difficult to insert. Proper alignment of the arch beams was an absolute necessity in order to get the pins in the holes. The tolerance between the pins in the holes was quite small due to the fact that the arch beams were also used as gutters to carry the water down the side of the building. The pins could have been tapered on 1/2 to 3/4 inches of each end of the pin, thereby allowing the pin to align itself as it passed through the arch beams.

The filler pieces that went above both the metal and fabric doors and around the personnel entry doors in the metal end wall were secured to the framing members by J-bolts. These J-bolts passed through the specific piece of panel and attached around the arch beams or the door rails. This method of fastening the panels into the building system was somewhat lacking because it did not provide a positive lock into the building components as the other panels and beams did. They were fabricated out of a light corrugated aluminum material the same as the metal door in the side personnel entry.

After the erection of the shelter was completed, it provided what appeared to be a very good facility, capable of withstanding the local environmental conditions and the test program planned for the shelter.

SECTION IV

SHELTER TESTING

1. General. The shelter test program began in late December 1973 and continued through August 1974. The program was devised to test some of the components individually, combinations of components and the whole shelter system to ascertain its durability and operational capability to satisfy a worldwide deployment requirement.

Some of the problems encountered on previous shelters of the transportable nature had been that the erection system required the use of special tools and equipment, excessive manhours to erect, cumbersome operations and a lack of watertightness. The test program primarily addressed these areas, particulary the ability of the shelter to withstand extreme environmental conditions and ease of operation. Other areas were also evaluated during the test program. The following paragraphs describe a chronological sequence of events that took place during the testing period.

2. Fabric Door Test. The fabric door test was designed to test the operational capability of the door, the time to open and close, the size of the opening that an aircraft required to enter the shelter, the repair capability of the door in the event of damage, and the durability test to observe the door operation after the shelter had been erected for an extended period of time.

The door opening and closing system consisted of two winches on each side of the shelter that were mounted to the first arch beam. The winches operated cables connected to each door and by operating these winches,

the door traveled across the top guiderail and then pulled up at the sides. The door could be opened by one man if necessary. This would require an individual to open on side of the door and then go to the other side of the shelter and operate the winch from that side. A minimum of two individuals were used in opening the door during the test program to record the time to open the doors from each side simultaneously. Figure 38 is a schematic of a cable system for the opening and closing operation of the fabric door. To open the door, the winch was operated and drew the cable that went up to a point on the arch and then down through the fabric to a point at the bottom of the center vertical support beam. This cable drew the door to the open position from the bottom. As the cable was drawn on the winch, force was exerted on the bottom of the vertical beam and pulled it to the side. As the beam traveled on the top roller rail, it contacted the next vertical beam and the door continued to operate toward the side. In opening the door, it was found that the vertical beams had to be constantly twisted to keep them moving in the upper rails. The bearings that traveled inside the top rail moved easily, but as increasing tension was experienced on the cable, the vertical beam had a tendency to twist. As the beam twisted, it bound in the top rail and stopped the travel. A man twisting the beam could free the bearings at the top and the cable winching could be continued. If the top roller rail had a piece of angle iron as a guide for the vertical post to keep it straight as it traveled across the beam, this problem could have been overcome. Other than the beams binding, the door operated well to the half open or

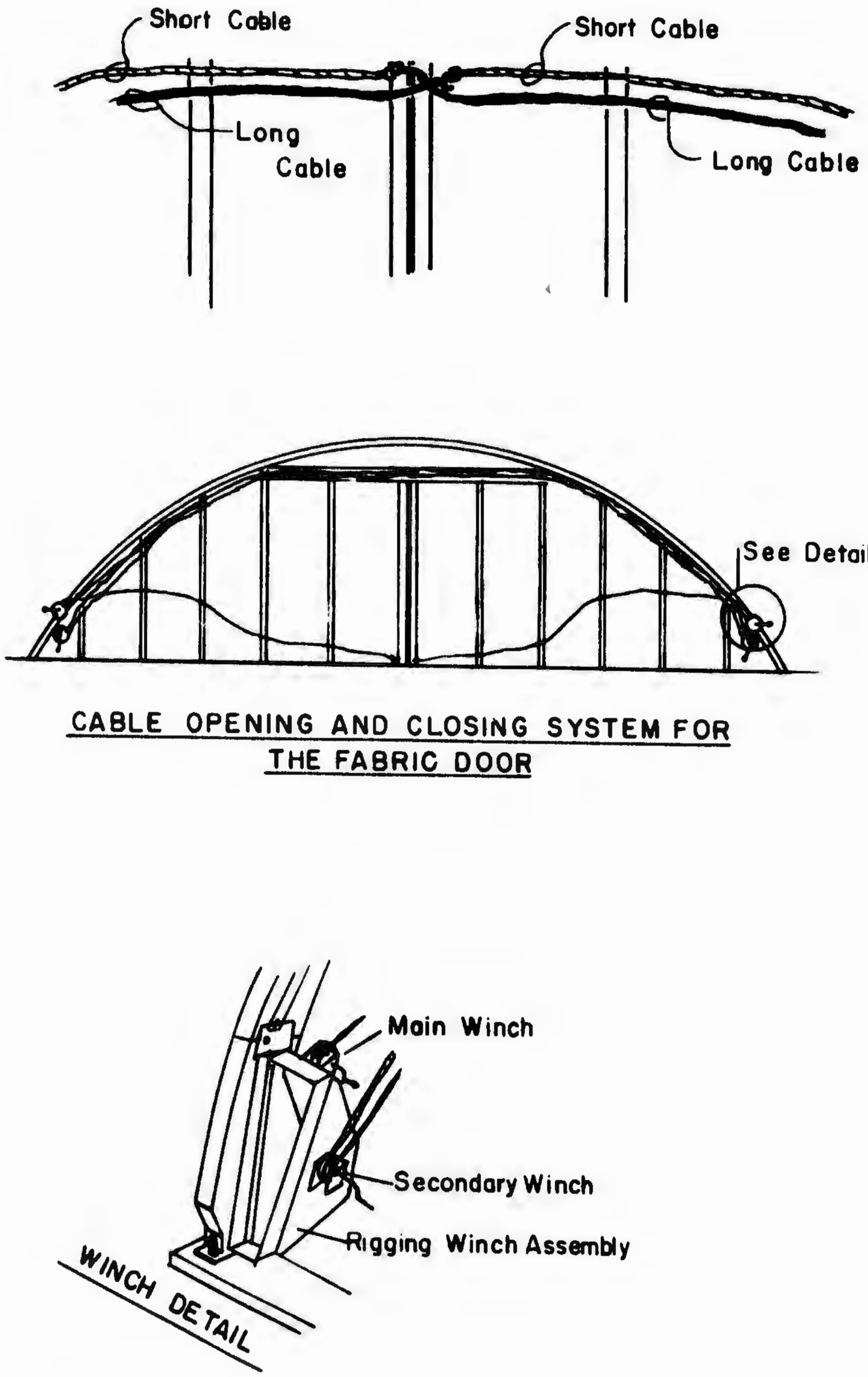


Figure 38 Schematic of Cable Opening and Closing System For Fabric Door With Winch Detail

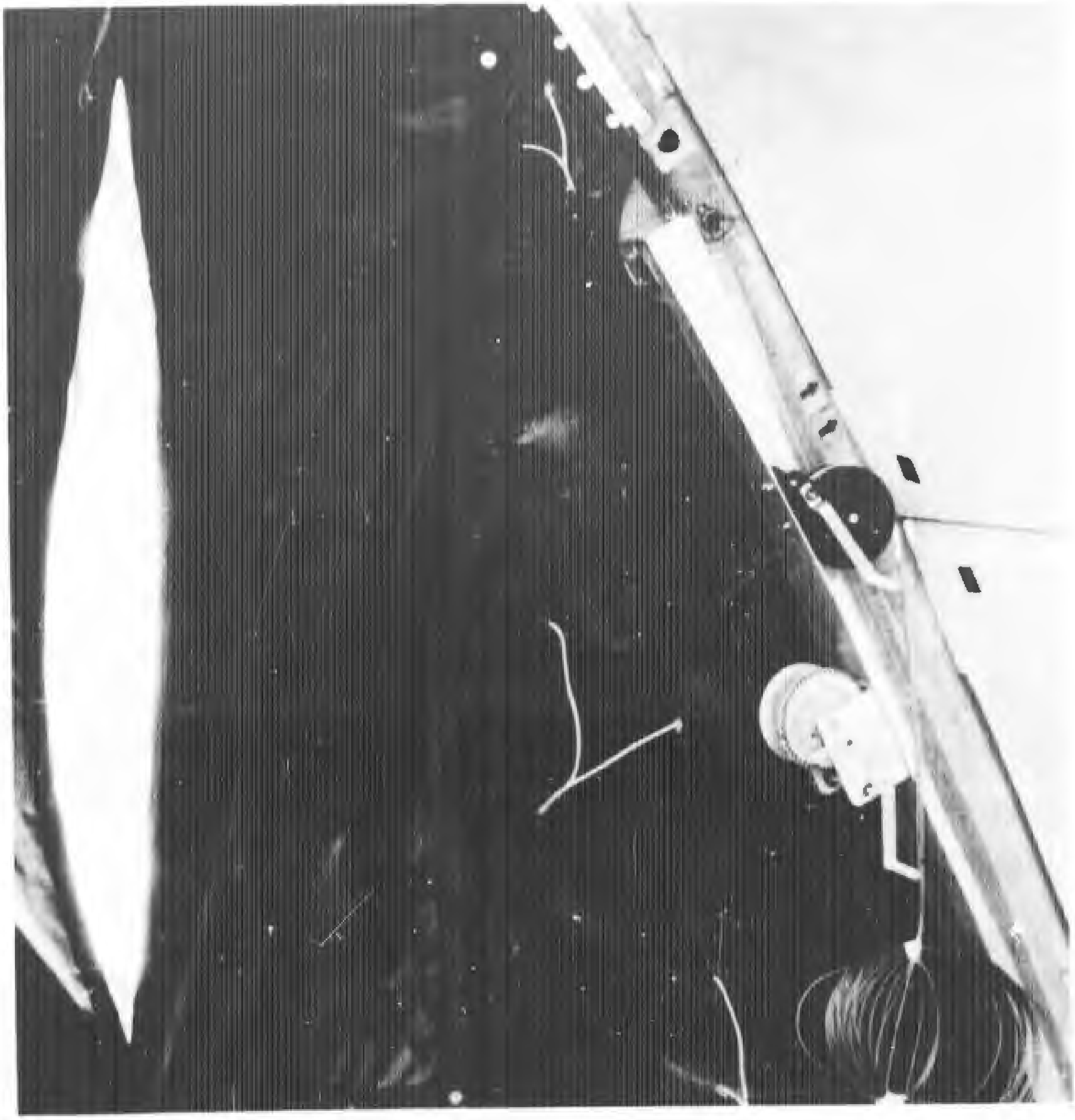


Figure 39 Fabric Door Cable Winch, Personnel Door
Side of Shelter

truck entry position. At this point, as the cable was continued to be wound on the winch, the top of the vertical support beams reached their full travel distance on the roller rail and pivoted from that point. The bottom of the beam then moved up at an angle and gathered at the side of the building. Figures 39 and 40 show the winch systems

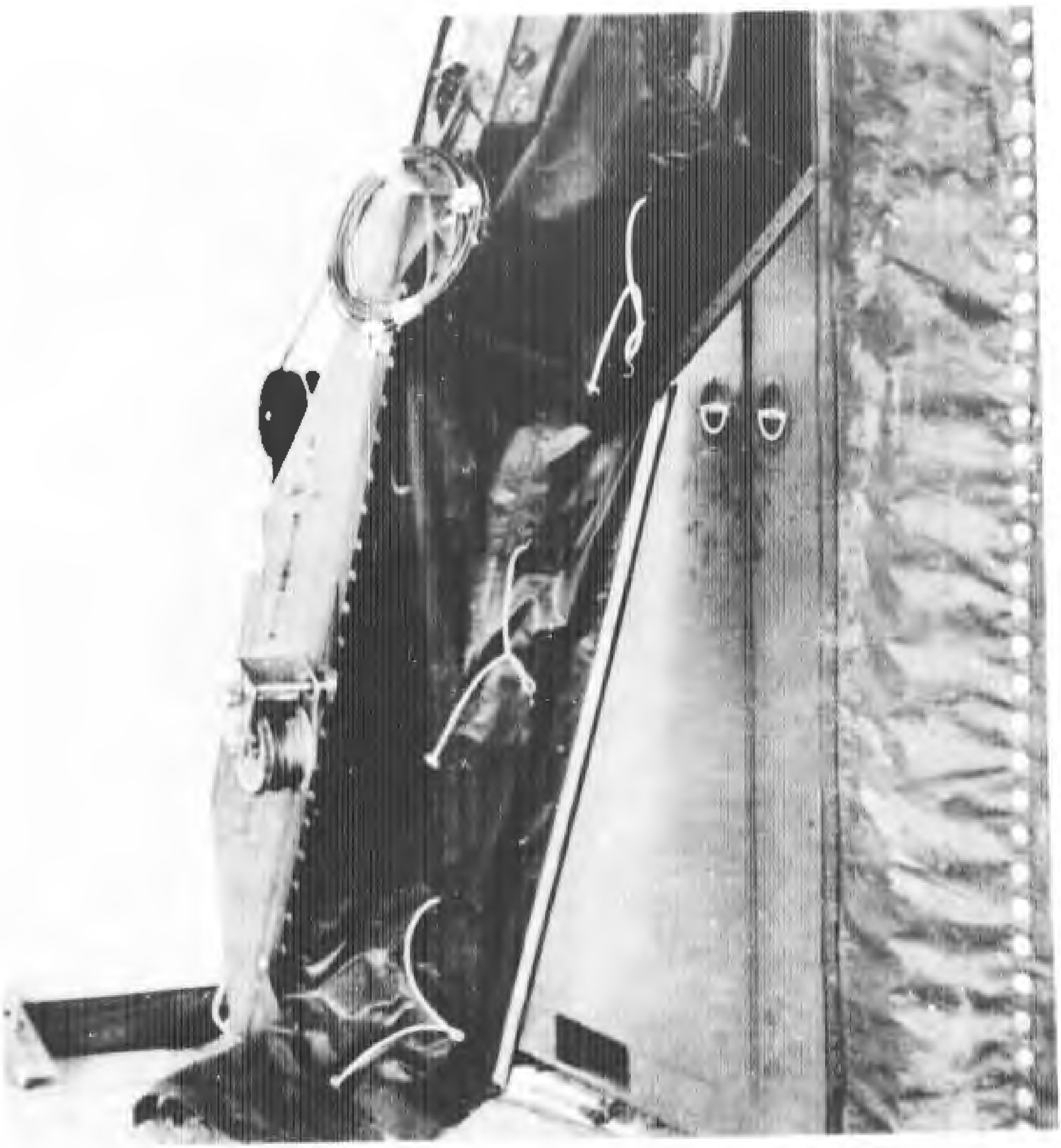


Figure 40 Fabric Door Cable Winch, Container Side of Shelter

that operated the door. As the vertical beams were picked up higher from the ground, it became necessary to fold and tuck the fabric to allow the beams to go up as far as possible. This operation had to be accomplished with a person other than the individual operating the winch. Figure 41 shows the fabric door as it was being opened on the A-frame side of the building. When the door was opened to its

Figure 41 Fully Opened Fabric Door, Pers nel Door Side of Shelter

fullest extent, measurements were taken at different heights to determine the maximum opening position of the door to accomodate various types of aircraft (Figure 42).

Figure 42 Measurements Taken to Determine Width of Door Opening

Measurements recorded at a five foot and ten foot height were 46 ft 7-inches and 38 ft 4-inches respectively. A minor problem area was encountered when the door was in the fully open position. It was noticed that small holes began to appear in the fabric adjacent to the vertical

post. Closer examination revealed that the grommet fastening technique was damaging the fabric. The grommets were secured to the fabric by a metal disk on the rear side of the door and the head of the grommet was held by a screw (Figure 42a). As the door material was gathered, the screw started puncturing the fabric door. This

Figure 42a Metal Disks Holding Grommets

problem could have been avoided with another nut on the end of the screw on the inside of the door. The sharp end of the screw was causing the damage to the fabric. The small holes that were created by the screw end of the grommet were tested to see if any further damage would occur to the fabric material. By inserting one's finger in these holes and pulling, no further damage resulted to the fabric. It could not be torn but apparently did not resist a puncture to a great degree.

The door closing method was by operating a winch, this time on the opposite side of the shelter. The opening winch system was released and allowed the vertical beams to pivot back from the full open position to the truck entry position. The winches were then operated to draw the center vertical beams across the building with the cable system. Very little binding action was experienced in the upper roller trolley rail and the closing operation was somewhat smoother than the opening sequence. When the doors were fully closed, the pipes that telescoped from the bottom of the vertical beams were unpinned and allowed to drop into the ground plates that were previously anchored in the sand. Figure 43 shows the center beams with the ground plate anchoring method. Underneath these ground plates was a cable that was pulled up into a cut-out on the telescoping pipes and a lock-pin was inserted through the pipe under the cable. This procedure locked the vertical posts into the ground and prevented door movement during high winds, etc. Figure 43 also shows the cable system as it was tied to the center post for opening the door. The closing method allowed the door to fit securely

Figure 43 Vertical Beam Telescoping Pipes Attached to Ground Anchor at the Center of Fabric Door

at the uppermost part of the center vertical beams but did not force the bottom of the vertical posts together. The slots that were cut in the ground plate to anchor the vertical posts were elongated holes and allowed the bottom of the door to remain open approximately three inches. This presented a problem during the wind test on the door. If a strap was attached to one side of the center vertical posts, the

doors could have been manually forced together in the closed position and a strap attached between the vertical beams to hold them securely closed. After the initial opening and closing operation, the door was completely cycled ten times to determine an average time for opening and closing and to observe any other problems that might occur. As the opening and closing of the door progressed, the personnel operating the winches became more familiar with its operation and the time improved as the test progressed (Table III). Several problems were noted during this test with reference to the opening cable wearing various components of the door. Figure 44 shows where the cable had worn the slot in the vertical support beam as the door was cycled. The beams were

Figure 44 Cable Wear on Vertical Beam After Door Test

TABLE III

Fabric Door Cycling

Opening

Cycle No.	Time (Min)	No. of Personnel
1	25	4
2	22	4
3	20	4
4	21	3
5	17	3
6	23	4
7	20	3
8	17	3
9	17	3
10	14	3
	19.6 (average)	

Closing

Cycle No.	Time (Min)	No. of Personnel
1	20	4
2	17	4
3	18	4
4	19	3
5	17	3
6	21	4
7	17	3
8	13	3
9	13	3
10	10	3
	16.5 (average)	

fabricated of aluminum and the rubbing of the steel cable caused wear at all the openings where the cable passed through the beam. This problem continued as the door operation continued. In a long term usage, this slot could be beefed up with a non-corrosive steel insert and reduce the wear on the aluminum beam. Figure 45 shows the folds that develop in the fabric as a result of the door cycling and the wearing of the fabric by the constant friction of the opening cable

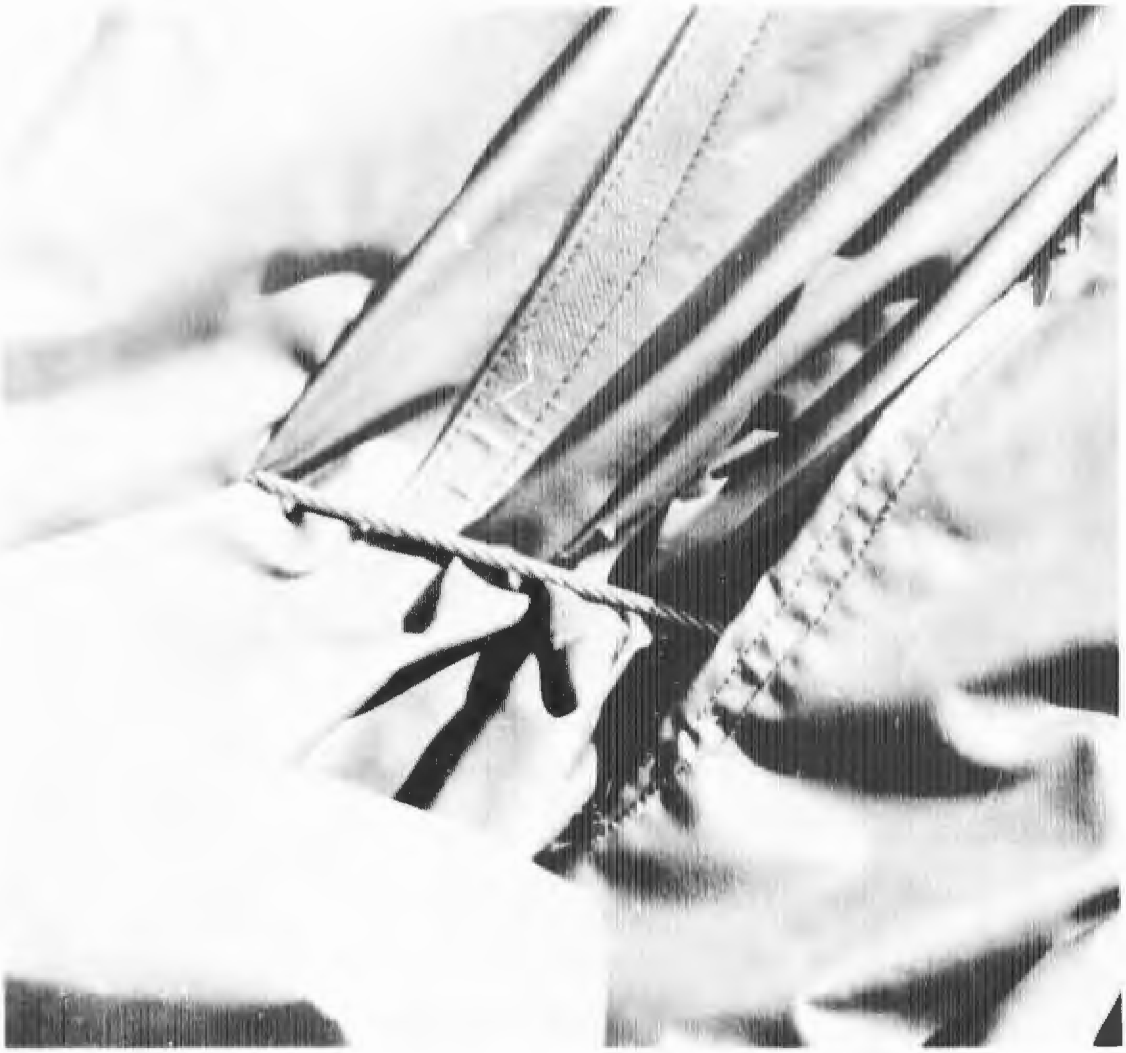


Figure 45 Cable Rubbing on Fabric as Door is Opened

during the operation. Figure 46 is a hole that developed in the fabric itself because of the pinching action caused by the cable on the fabric rubbing against the aluminum.

Figure 46 Tear in Fabric Caused by Cable Friction

Figure 47 shows where the cable passes through the uppermost part of the nonpivoting vertical support posts and then down to the winch. Considerable wear was experienced at this point both on the aluminum and the fabric material.

The fabric door was fitted with two personnel doors. The building system initially provided for entry through the container. In the final field configuration, four containers were to be utilized for

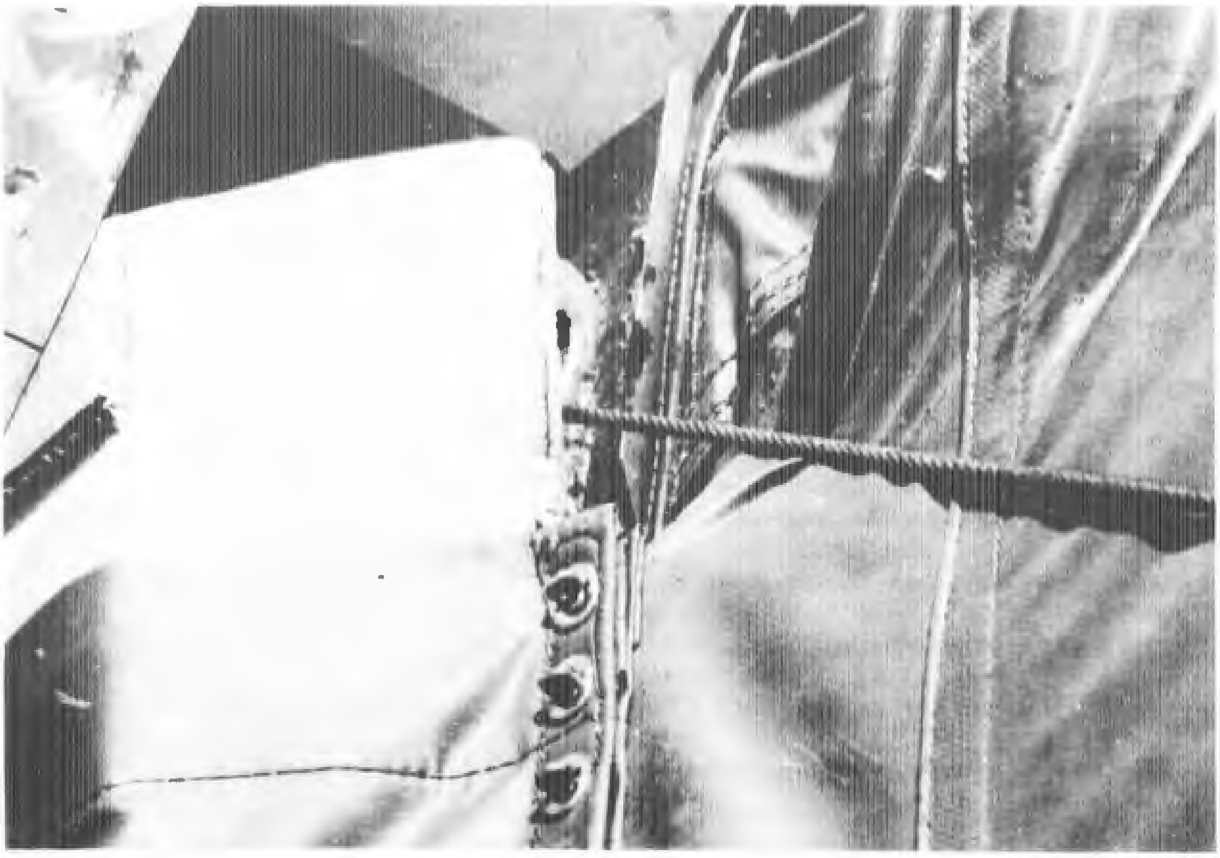


Figure 47 Cable Wear Experienced at Vertical Support Post

entry into the shelter. As previously described for the purposes of this test program, only one container was provided in the contract to provide testing of the proposed system. The side closures for the end wall consisted basically of a fabric material between the arch beam and the vertical support beam that was hooked to the container. The attachment method was by use of a rail similar to that used on the panel to panel connection. This was bolted onto the exterior of the container and the arch beam and then a similar rail was attached to the edge of the fabric and locked the fabric transition from the shelter

arch beam to the container. This system was satisfactory but did not provide a total weather-proof shield. Some water did come down between the container and the transition piece. Also during the 7-month period of the test, the base channels spread a little and the door from the container was not able to be fully opened because of the movement. The exact positioning of the container was required in order to open and close the door into the shelter (Figure 40).

The personnel door that was designed for entry on the opposite side of the shelter through the A-frame was a fabric door manufactured of the same material as the main door. It attached to the fabric closure wiht grommets and was hinged at that point. The other three sides of the door were provided with a velcro material that had to be compressed against the end closure, to form the seal. The door was not rigid in itself and was not easily attached to the fabric. If a rigid frame had been provided both in the closure section and the door ifself, sealing of the door would have been much easier. During the test period, the door itself suffered no degradation from the elements, but the closing of the door was somewhat difficult because of its nonrigid configuration.

During the entire test program, the fabric door was left in the closed position, the truck entry position and full open position for extended periods of time to observe the environmental effects on the door. Figure 48 shows where one of the vertical support posts came loose from the arch beam. This particular post is the only one that did separate from the arch beam. The cause was constant vibration

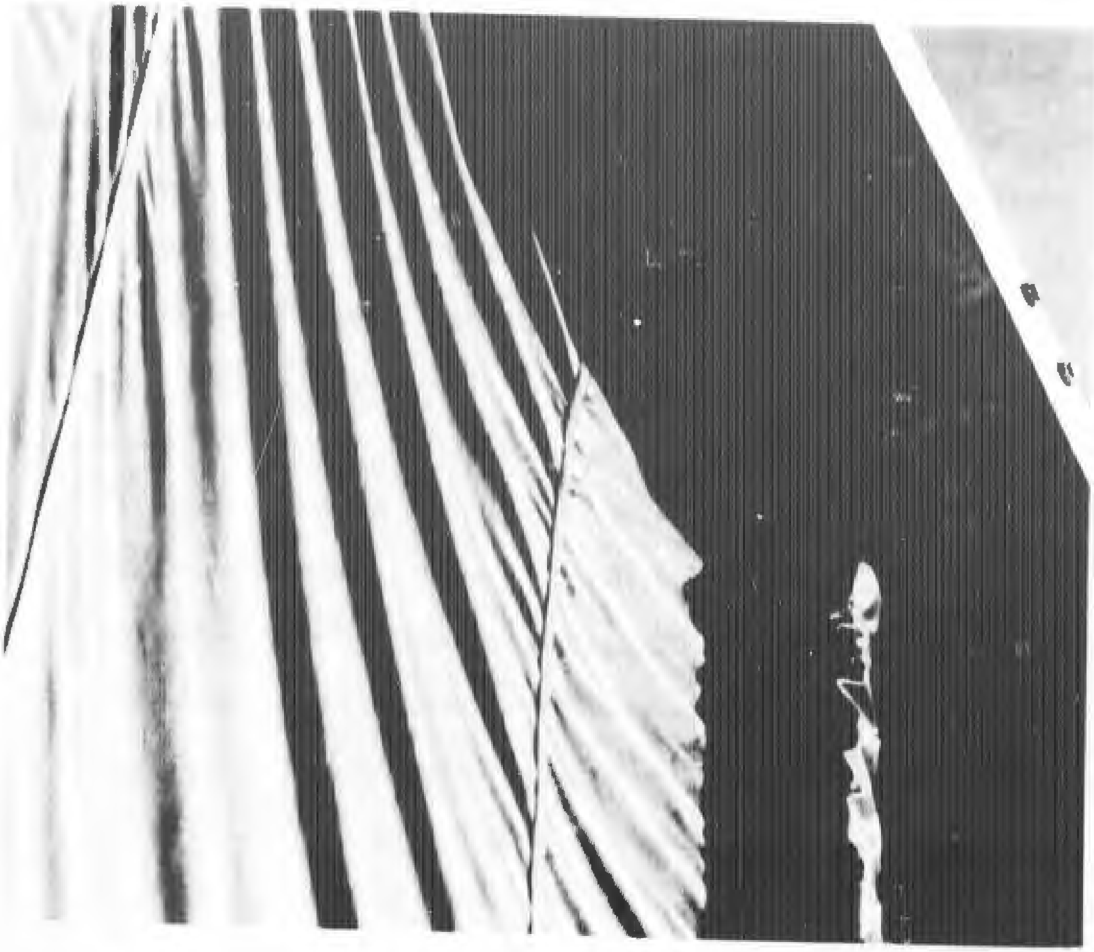


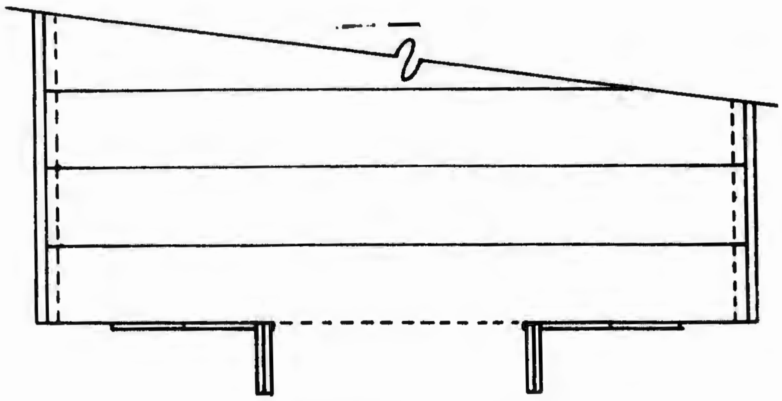
Figure 48 Vertical Support Beam Separated From Arch Beam

on the door from blowing wind. The vertical support post is held on the beam with a nut that is screwed onto the erection pin. This problem could easily be overcome with the insertion on a cotter-pin behind the nut to hold it securely in place.

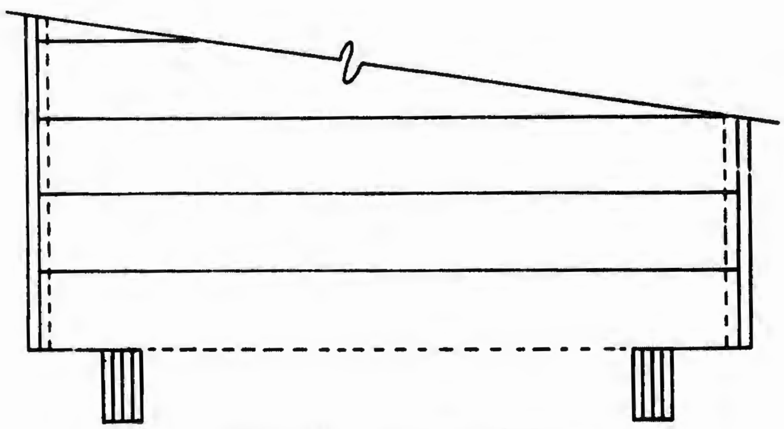
The bottom of the door was fitted with a ground skirt similar to that on the bottom of the panels. It was made of basically the same material as the door. The ground skirt was provided to take up any unevenness

in the ground and was secured with sandbags during exceptionally unfavorable weather. The test site was continually subjected to winds from 5-25 knots and some erosion occurred at the base of the fabric door. The fabric was not secured with sandbags during this test period. The wind caused the bottom skirt on the door to oscillate from the inside to the outside of the shelter, depending on the wind direction, and caused sand erosion in this area. At the completion of the first phase of the test, the door did not suffer any damage. In the closed position, the door did provide satisfactory protection from the elements and did not suffer any damage during the seven months it was erected. The operation of the door in the opening and closing method should be modified to allow for movement of the door without the complicated cable arrangement. Other than the opening method, the door functioned satisfactorily during the test.

3. Metal Door Test. Each side of the metal door consisted of two folding vertical sections that moved across the arch to the folded position. Figure 49 is a schematic of the door operation in the truck entry and full open position. Lockheed Company did an indepth study during the design analysis of this door to attempt to come up with a door that could provide the half open and full open position, withstand the high wind loads that the building was required to meet, and provide a configuration such that in the fully opened position, minimum door areas was exposed to reduce the possibility of damage during a high wind. The metal door was tested much in the same manner as the fabric door in that it was cycled a number of times to evaluate the opening



Metal Doors—Truck Entry



Metal Doors—Full Open

Figure 49 Plan View of Metal Doors

and closing sequence (Table IV). It was observed during an extended period to evaluate any damage or problem that might be encountered as a result of weather, wind, corrosion, etc..

TABLE IV

Metal Door Cycling (Open)

Cycle No.	Time (Min)	No. of Personnel
1	12	4
2	19	4
3	14	4
4	11	4
5	7	4
6*	22	4
7	17	4
8	14	4
9	8	4
10	7	4
	13.1 (average)	

Metal Door Cycling (Close)

Cycle No.	Time (Min)	No. of Personnel
1	19	4
2	17	4
3	14	4
4	13	4
5	8	4
6*	15	4
7	12	4
8	10	4
9	8	4
10	8	4
	12.4 (average)	

(*) Cycles 6-10 were conducted thirty days after first tests were conducted.

To open the metal door, a keeper that locked the top portion of the door into the arch beam had to be extracted. This was done by means of a nylon rope that was attached halfway up the vertical beams. When the rope was pulled, it released that portion of the door from the arch beam and enabled the door to be pushed along the upper rail which carried the weight of the door. The bottom of the door was guided by a rail that was anchored into the ground. Vertical telescoping pipes extended out of the vertical beams to guide the door at the bottom along the rail. These pipes were locked up inside the vertical beams with a lock pin mode during the shipping. When the door was erected, this pin was withdrawn and the pipe telescoped down onto the ground rail. It was left unlocked at this point to allow for the door to absorb unlevel ground elevation. To open the door, the keeper on the inner section was released and that portion of the door pushed outward. Then the door was pushed horizontally to accommodate to the truck entry position (Figure 50). Some difficulty was experienced in opening the door because of the binding of the top part of the door in the upper horizontal guide rail. Figure 51 shows the metal door in the half open position. This configuration is about eight feet wider overall than the fabric door half open position. The design provides that the ground rail is not required in the center portion of the building. (The area that opens to the half open position.) A ground rail is required from the half open position to the full open position area. This is because the center section of the

Figure 50 Metal Door Being Opened to Truck Entry Position

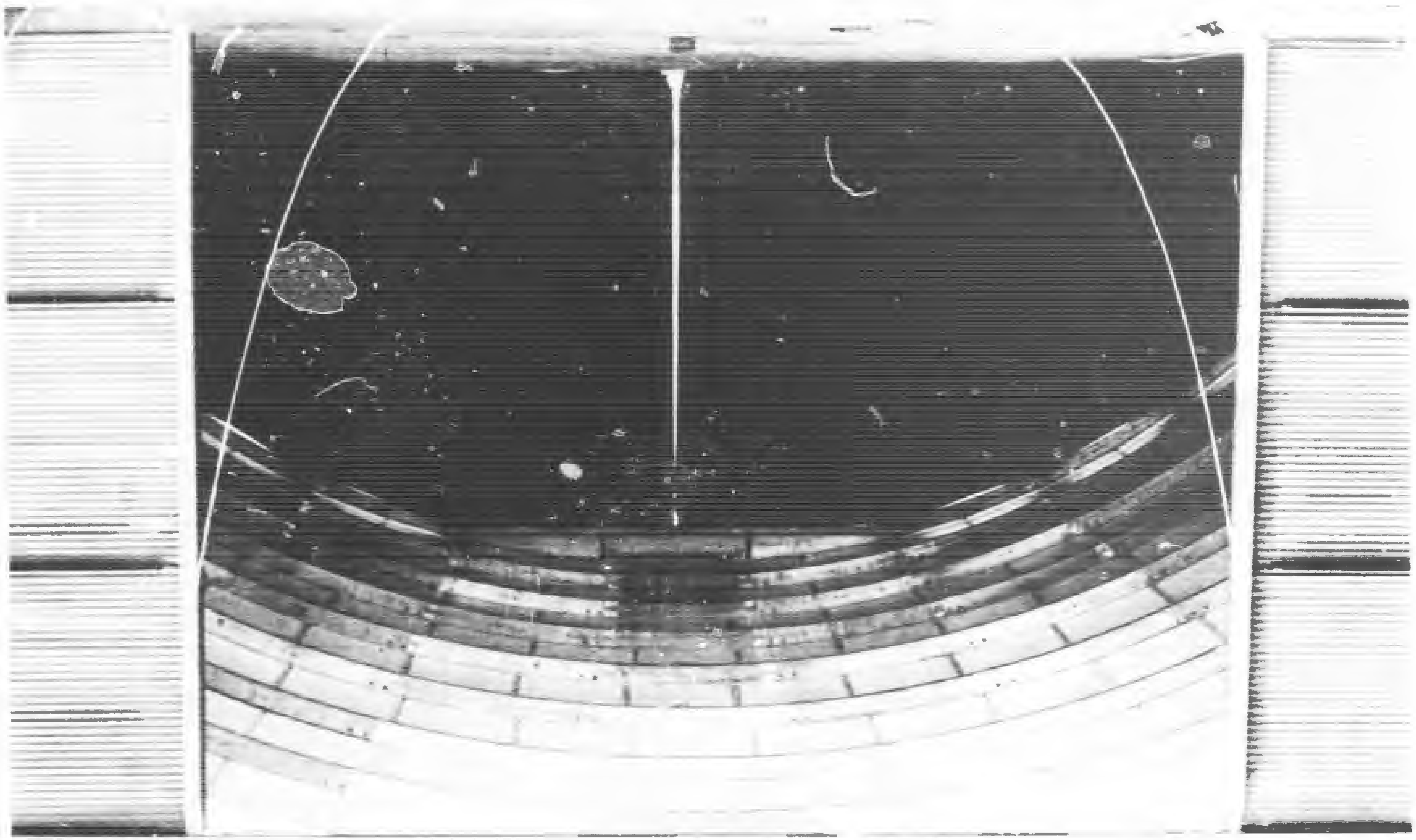


Figure 51 Metal Door in Half Open Position

door rides along the ground rail to the outer extremity of the building. To open the door to the full open position, a second keeper pin must be released where the door rides in the upper rail. This allows the center of the two sections to be released from the rail and then the door is folded as shown in Figure 52. Difficulty was experienced moving the door along the upper guide rail because the building was somewhat distorted during the first erection,

Figure 52 Metal Door Being Opened to Full Open Position

due to the ground elevation. This caused the upper trolley rail to be unlevel. As the personnel tried to open the door, it bound in the upper trolley rail. The keeper release ropes were used to pull the upper portion of the door laterally as it rides in the rail and physical force is used at the bottom. Figure 53 shows the vertical beam inside the trolley rail. When the beams started to twist,

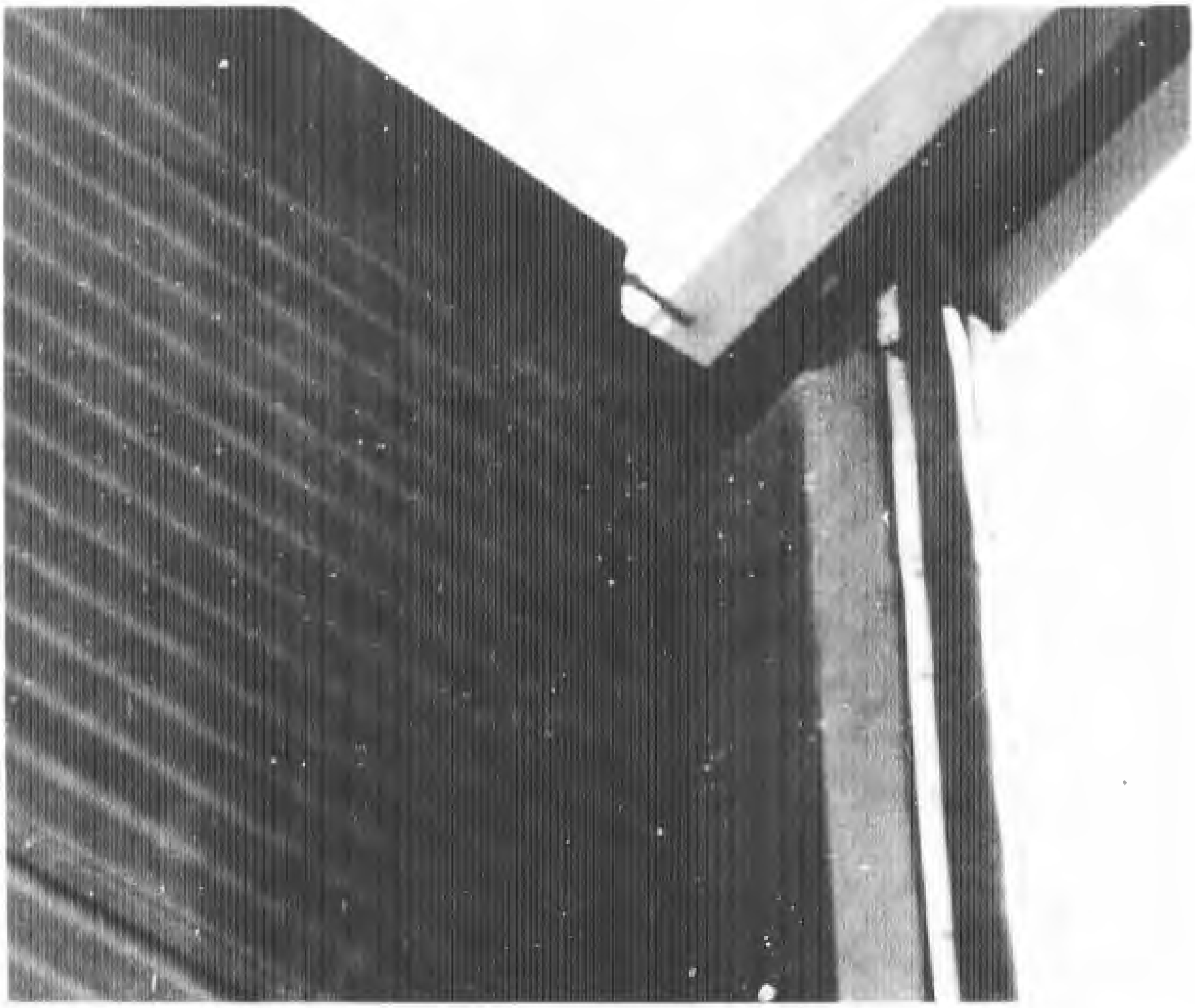


Figure 53 Vertical Beam Binding in Upper Trolley Rail, Metal Door

it bound inside the rail and had to be released by either pulling the door back toward the closed position or using a piece of equipment to get up high enough to force its release. Figures 54 and 55 show both sides of the metal door in full open position. When both sections are

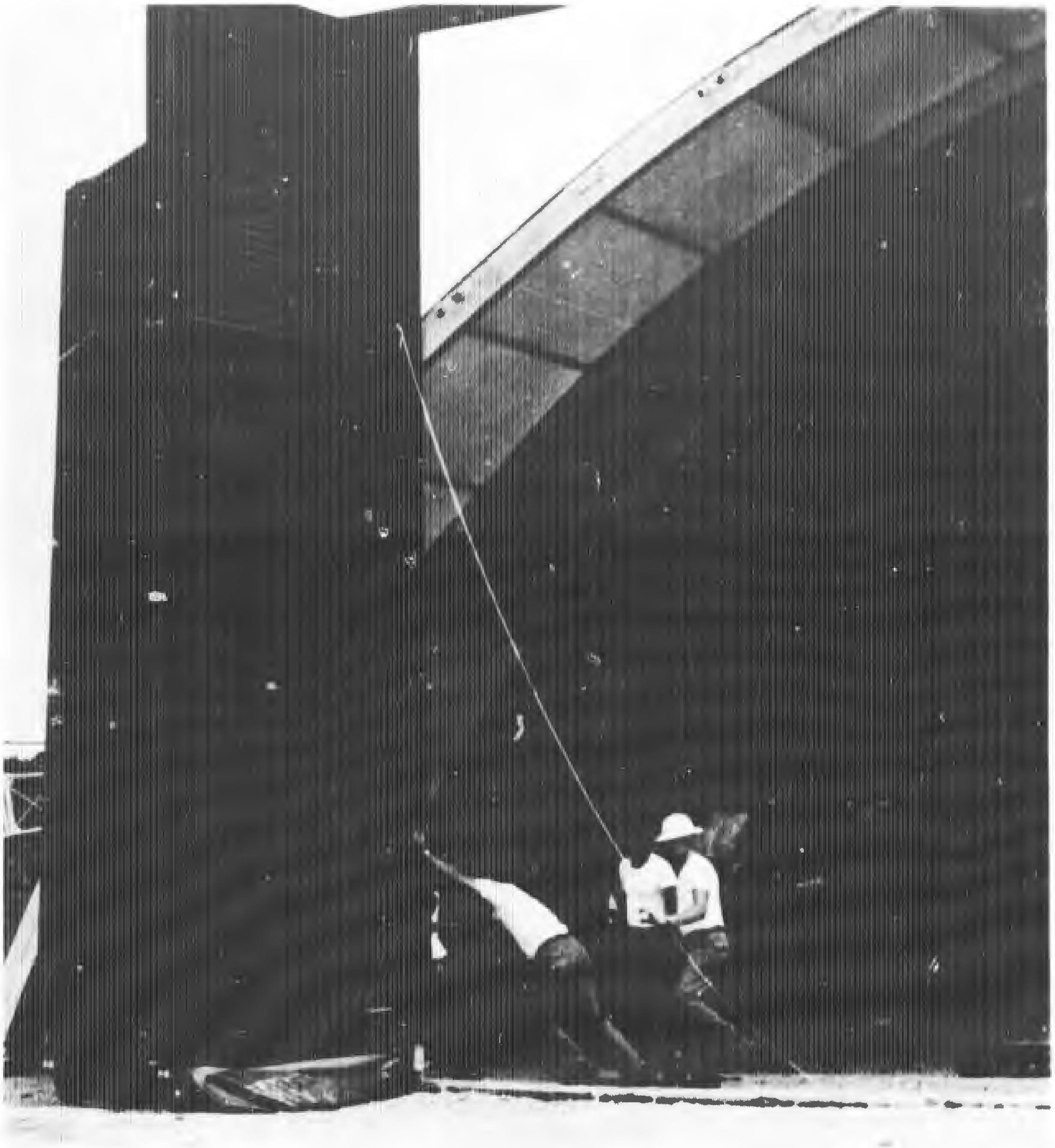


Figure 54 Metal Door Fully Opened Right Side

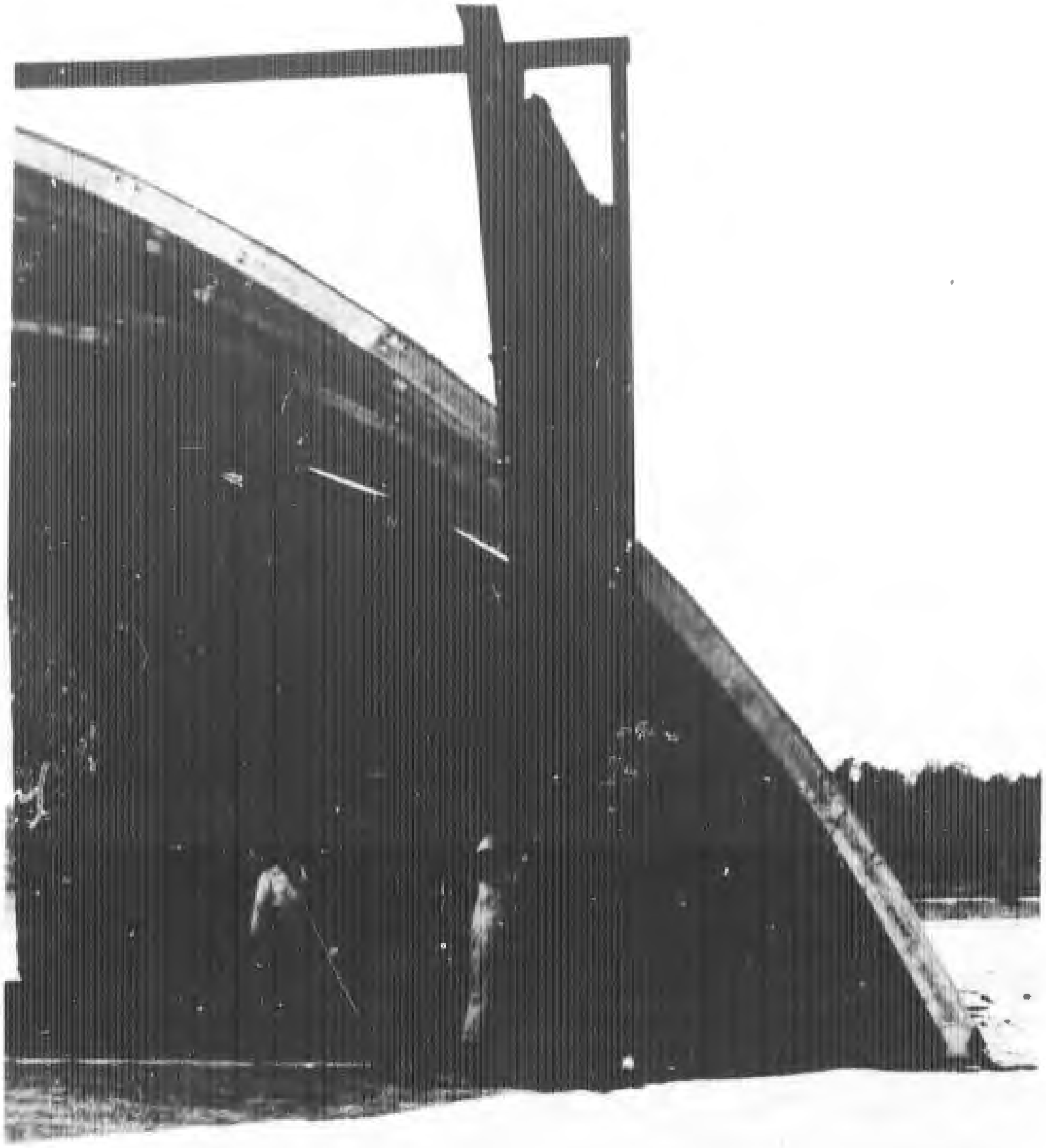


Figure 55 Metal Door Fully Opened Left Side

pushed together on each side, there is a nylon strap with a ratchet on the inside face of the beams to tie the two vertical beams together and secure the door in the open position. The original design concept for the door was predicated that a container would be located in the corner of the building to allow the door, in the full open position, to

be anchored. Additional tie attachments were necessary for the door without the container to hold it in place because of the large area that was exposed to the wind.

The door has a ground cloth attachment similar to the side panels and fabric door to prevent the elements from entering the shelter during extreme weather conditions. It attaches to the bottom panel on the door and did not provide any obstacle for opening the door. The closure panels at the outside sections of the arch between the door and the extreme outside edge of the shelter were fitted with corrugated panels and personnel doors. These panels were attached to the arch beams with the use of J-bolts and hinge pins. The method of securing these panels was satisfactory initially; but, during the extended time the building was erected, the constant wind caused loosening of these connections. The personnel door did not fit properly in the panel. This was due again, to the unlevel area at the erection site. Had the ground elevations been the same, the door would have fitted properly (Figure 56).

The metal door was cycled as the fabric door was to determine the average opening and closing time. More manpower was required to open the metal door than the fabric door. Once the keeper pins were released and if the door moved in the trolley without binding, it could be opened very quickly compared to the winch operation on the fabric door and provided an opening of 56 feet 11-inches. The problem encountered was the vertical beams binding in the upper track trolley and was restricting the door movement. Another problem that was discovered

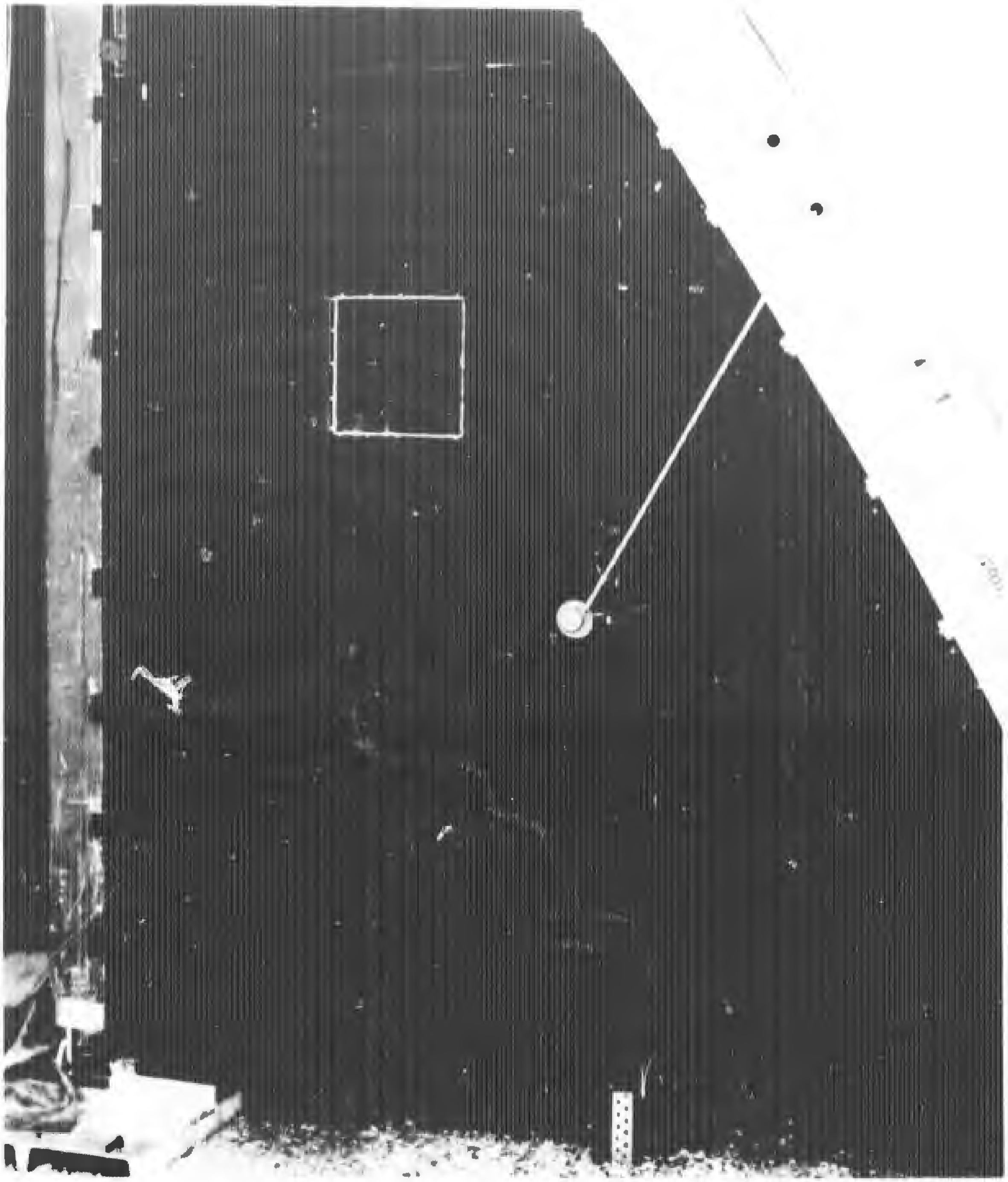


Figure 56 Personnel Door, Metal End Closure

was the roller in telescoping pipe that fit over the bottom guide rail came out several times because the screw that held the roller kept loosening. This problem was easily solved by putting an aluminum tack weld on the screw to hold the roller in place (Figure 57). Table IV shows the times required to open and close the door during the cycle period. It was opened and closed several times in addition to these but the door kept binding, particularly on the left side in the upper

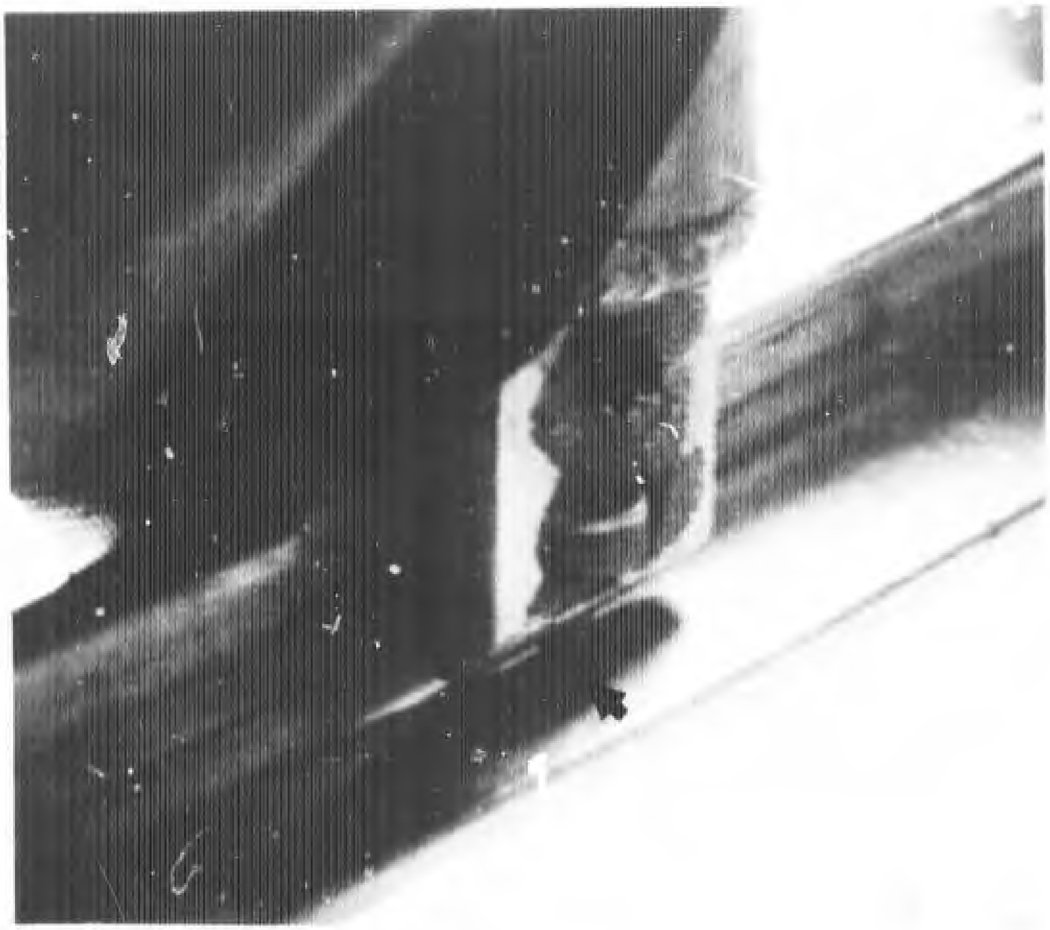


Figure 57 Screw Coming Out of Roller on Lower Guide Rail, Metal Door

trolley. Again, this is primarily due to the unevenness of the ground and caused the upper rail to be off a horizontal plane. Overall, the metal door was much quicker to open than the fabric door and provided a wider opening on the whole vertical height but this reliability was somewhat questionable.

4. Water and Wind Test. Approximately two weeks after the building was first erected and before any water tests were carried out, the building experienced a heavy rainfall. Many leaks were noted throughout the structure, particularly near the perimeters of the building. It was discovered that some slack had come into the panels; therefore, all the archs were retensioned. After they were tightened, some of the leaking did stop but not completely (Figure 58). Only one leak was noted in the panel to panel connection. Water testing on the shelter after the first erection was primarily carried out with the use of a fire hose. Personnel conducted the test on different areas around the building and by applying water to the various components to ascertian if any specific areas were vulnerable to the leakage. Water testing with the fire hose then proceeded to observe if the structure inherently leaked or erection deficiencies resulted in the leaking. Spraying water on the top of the building and letting it free fall on the top created a buildup of water running off and down the sides. As this water ran down over the panels, a great deal of water also entered the arch beam, which was, of course, the drain. As the water accumulated in the arch beams, water was noticed splashing out of the arch beams at the beam connections and also carrying over the arch beam and down the side of the beam. This problem was

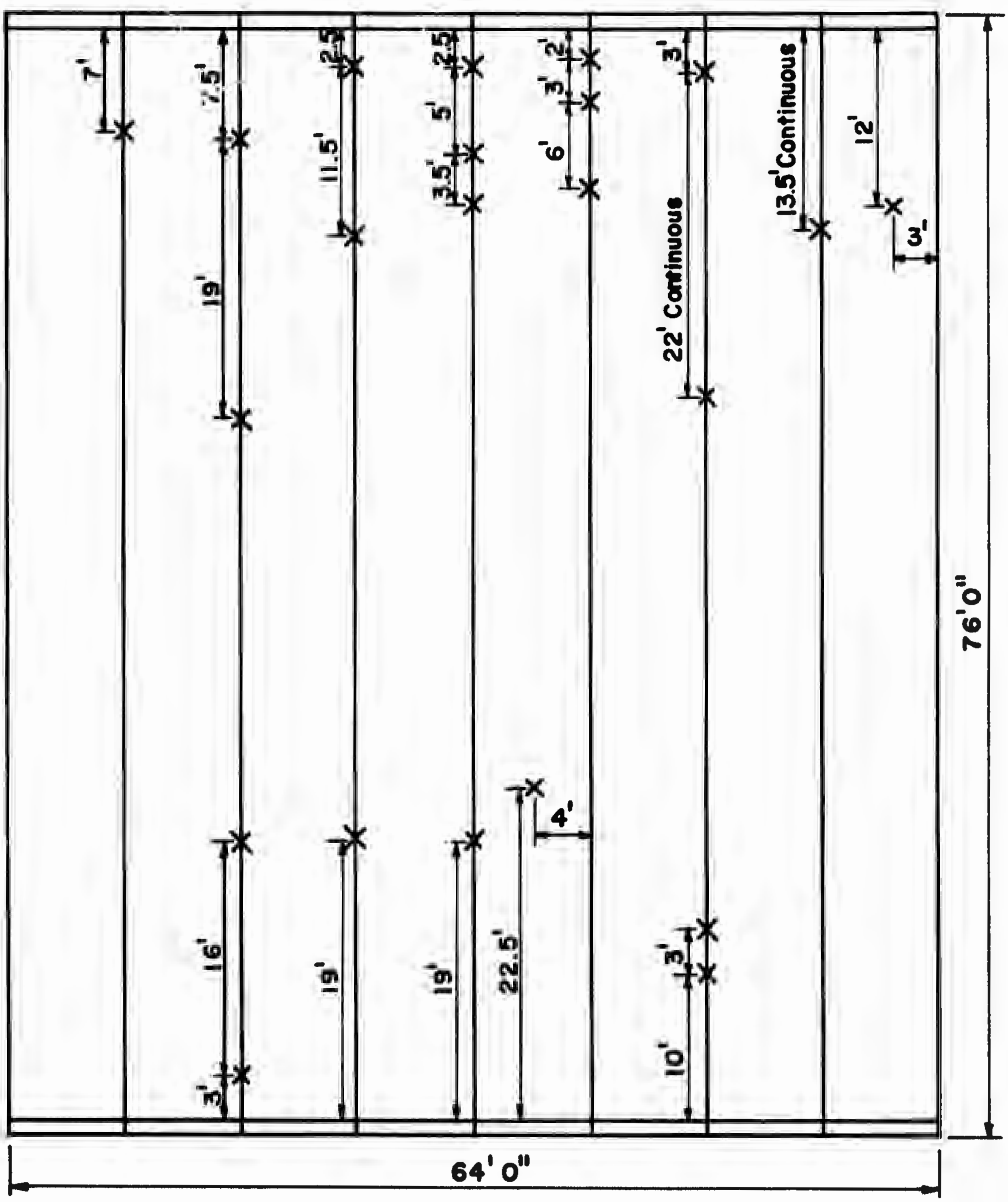


Figure 58 Water Leakage Points After Rainfall

multiplied the further down the arch the water was allowed to travel. Figure 59 is a detail of the arch beam and the cutout that allowed the water to fall into the arch beam and subsequently be carried down the arch to the drain. The Lockheed Company was notified of this problem. Lockheed accomplished a field fix on two of the arch

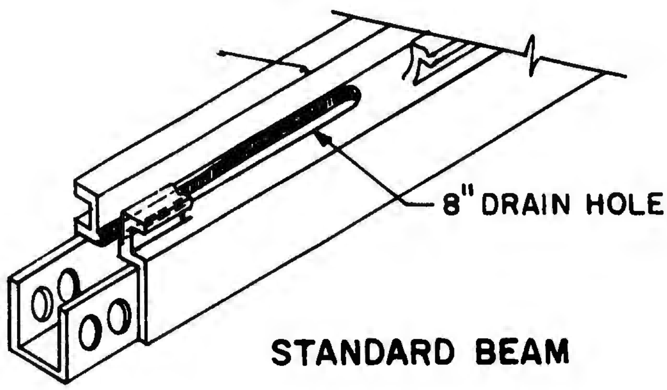


Figure 59 End of a Typical Arch Beam With Cutout For Water to Enter Beams

beams at the two lower areas by cutting out an additional piece of aluminum to enlarge the hole and thereby allow more water to fall into the arch beam. This modification was made only on four beam sections and would be required throughout the whole building in order for all arch beam segments to be interchangeable. This modification did resolve some of the problem, but it was evident that water was still coming in the building at the track on the arch beam where the panel insert did not completely enclose it. Another problem that was noted was that it made a difference on which side of the shelter the water was allowed to run down at the panel to panel connection. The locking joint on the panel, if it were overlapping down, carried

the water off much better than if the lock joint were turned upward to catch the water as it came down over the panels (Figure 60).

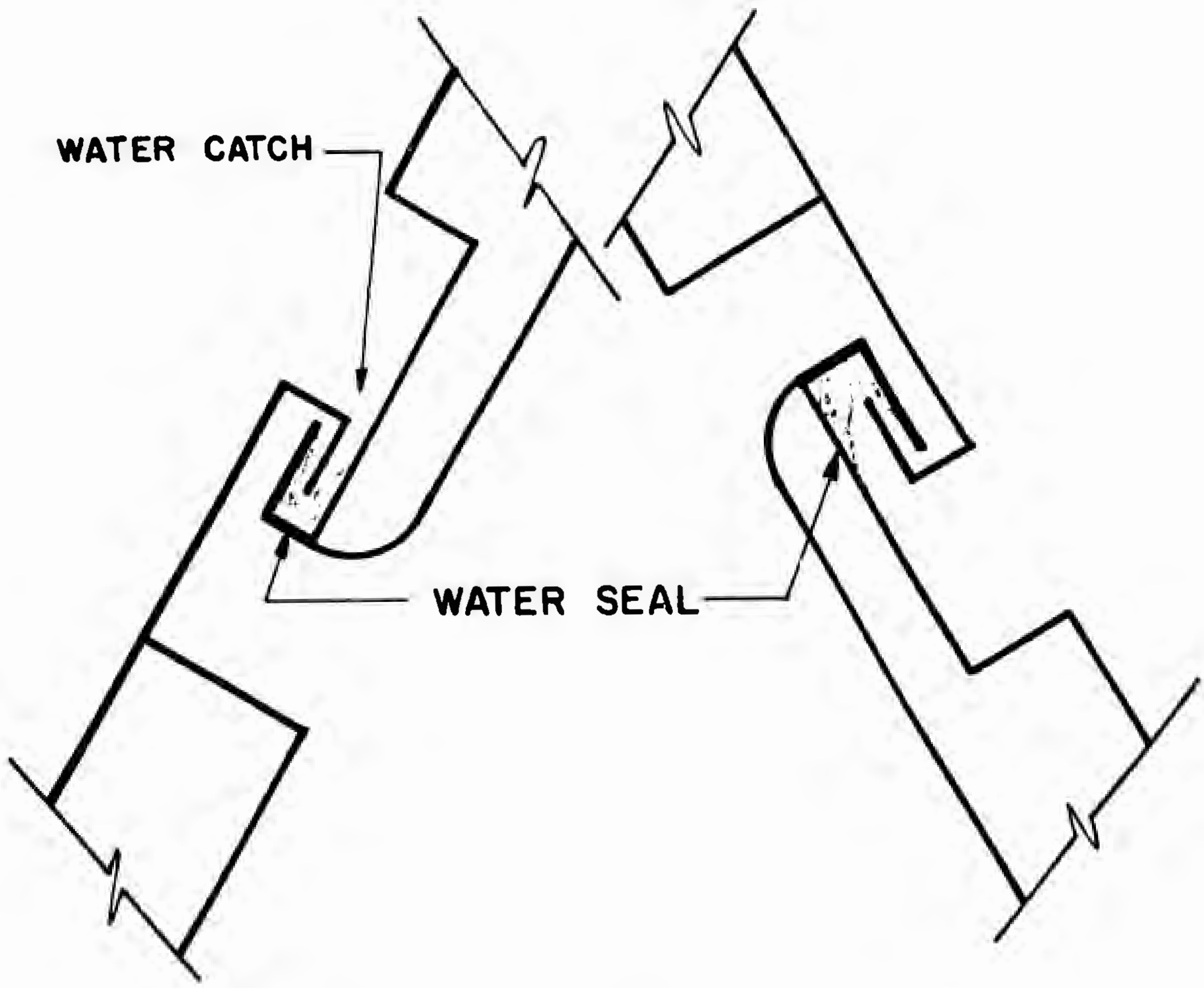


Figure 60 Detail of Panel to Panel Joints on Each Side of the Shelter

Expansion and contraction of the metal also played a part in the frequency of leaks in the panel to panel and panel to beam connections. During the morning, there were noticeably less areas that allowed water to pass through than in the heat of the afternoon. Further

tensioning in the afternoon did decrease this problem. One panel did separate at the panel to panel connection in the middle of the arch, although the ends of the panel were still joined. This, of course, allowed large volume of water to come into the shelter. Figure 61, is a typical example of the water testing that was accomplished on the building. One can observe that the panels are not in a horizontal line along the length of the building. This was due to the different ground elevations of the base rails.

Elevation of the base rails was taken immediately after the first erection and was again taken before the building was disassembled. Winds up to 60 mph were recorded on the wind measuring device from the south, southeast and east. The building did not experience any undue difficulties as a result of these winds. Figure 62 shows the difference in elevations from the first erection to its final position just before disassembly. The base rails spread approximately one inch on an average over the entire length of the shelter. The anchoring cables did show signs of slack since their initial placement, but the building was not damaged and considering the soil conditions, the shelter performed quite well.

During February, March and April, a wind recording instrument was set up in the vicinity of the building to record wind velocities and direction. The wind machine was incorporated into the test program after it was calibrated with the wind instrument to determine engine rpm required to attain specific wind velocities (Figure 63).

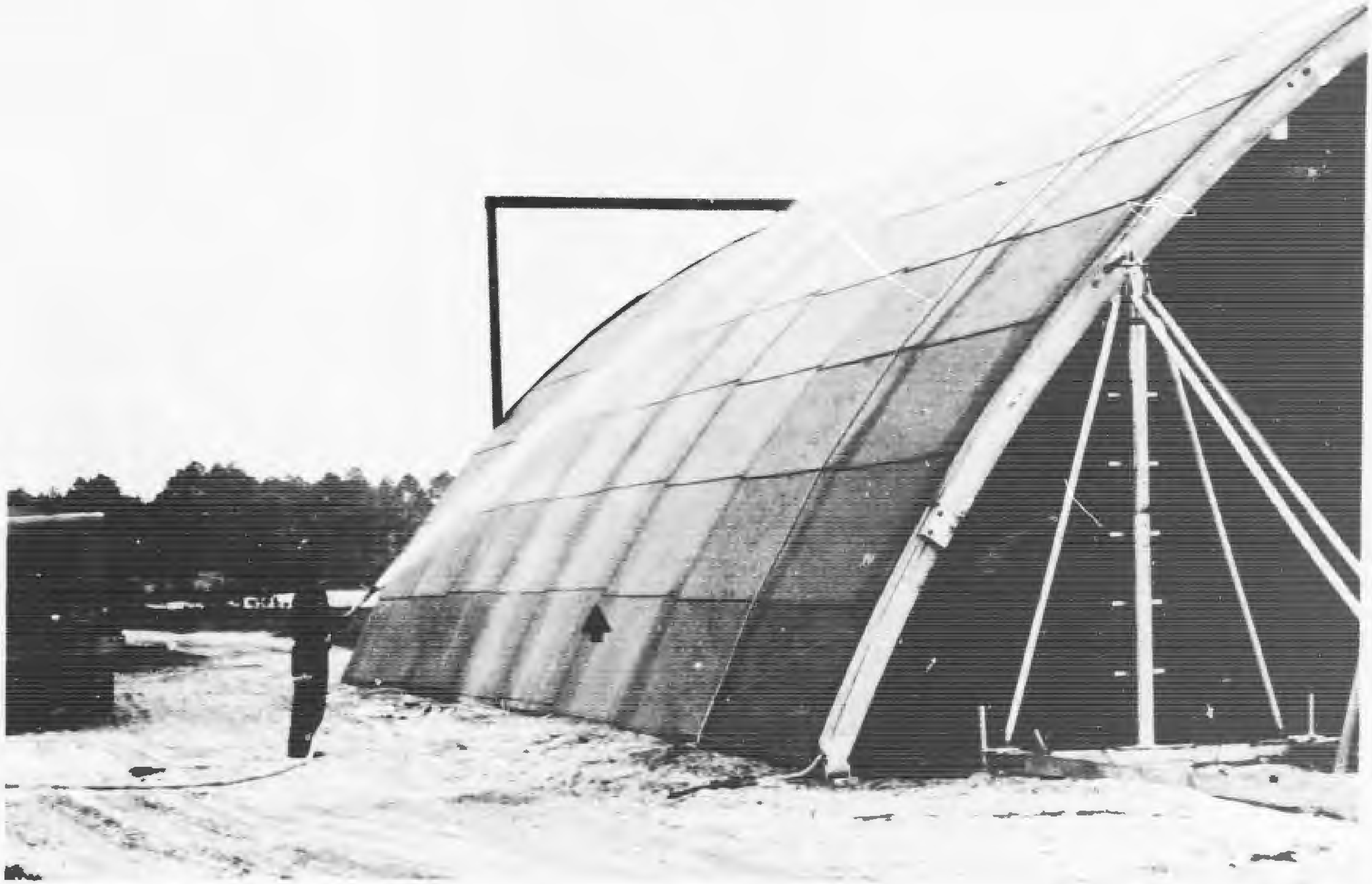


Figure 61 Water Testing on the Shelter

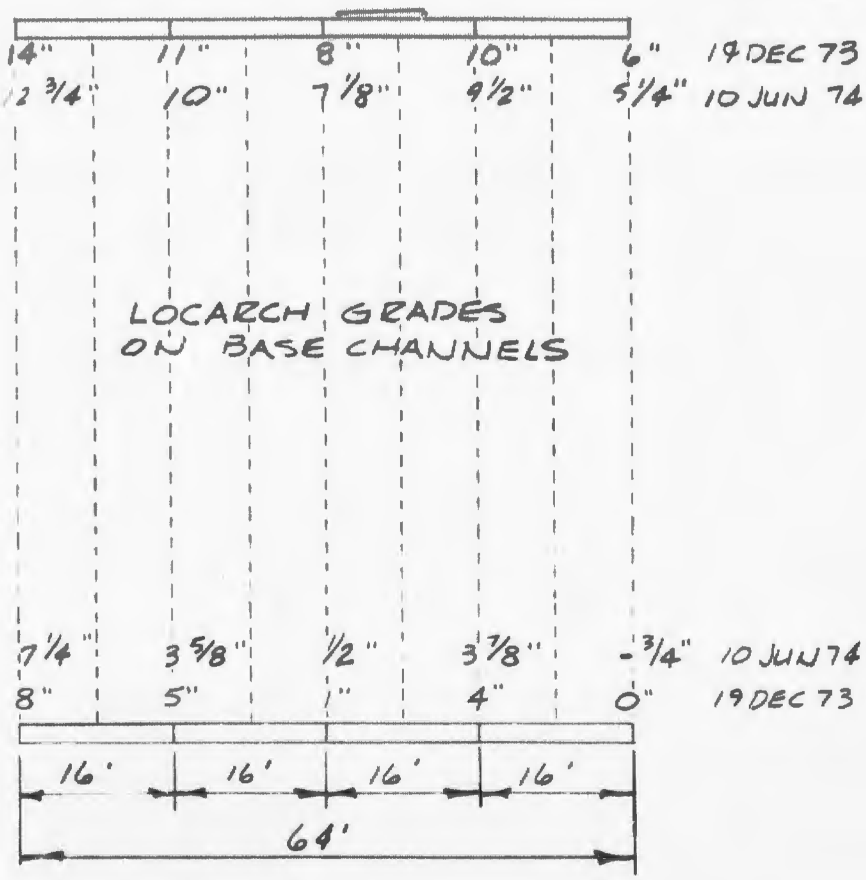


Figure 62 Elevations Taken on Base Channels During Six Month Test Period

Figure 63 Calibration of the Wind Machine With the Wind Recording Instrument

The wind machine was later fitted with a spray bar in the wind blast and hooked to a water tanker. Water was pumped through the hose to the spray bar to allow water to be injected into the wind stream (Figure 64). With this configuration, wind up to 60 mph and rain could be simulated. This method of testing was not used extensively during the first erection because of the difficulty

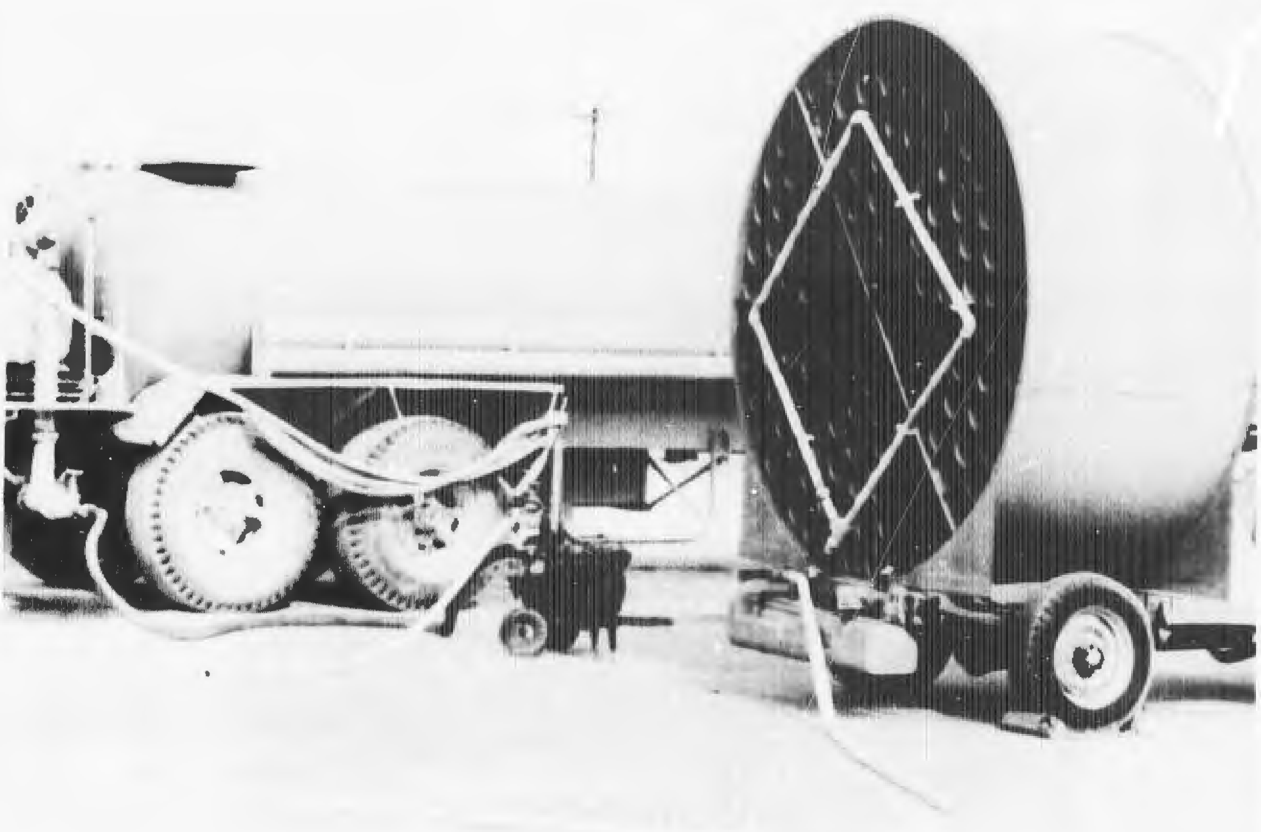


Figure 64 Wind Machine With Spray Bar Attached

in moving the equipment in the sand. (The use of this apparatus is described during the water testing on the second erection of the shelter.)

Strain gauges were also attached to the arch beam at different locations during the months of February through July. The mechanical strain recorders, manufactured by Technology Incorporated, Dayton Ohio, did not show any reading during this time period, although the building did experience wind loads gusting up to 60 mph.

5. Panel Testing. Panel testing revolved around the type of handling a panel would undergo in a field condition. It consisted basically of moving the panels in the palleted configuration, individual movement of the panels, installing the panels on the arch beams, disassembly and visual observation. The panels were also tested on a hard surface with the drop test. Figure 65 shows a panel being dropped from a three-foot height. Some panels were also dropped from a six-foot height and resultant damages were observed. Figure 66 shows the corner of a panel that was dropped from the three-foot height. The edges of the panel that had the channel or lock mechanism were quite vulnerable and could easily be distorted and deformed because they were fabricated aluminum extrusions. The lock mechanism could be easily be pried out with a screwdriver back to almost its original shape. The seal that was inside the channel lock sometimes did not provide the proper seal after the panel had undergone damage such as this. Figures 67 and 68 show the foamed insert for the panel that rides on the track and the damage sustained when dropped at the

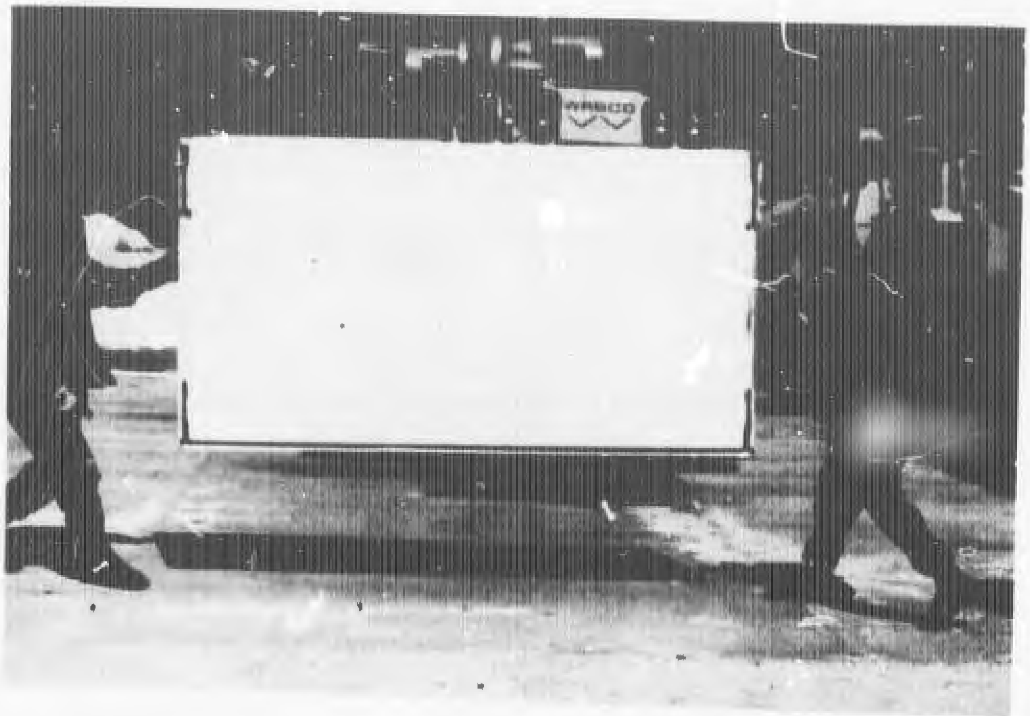


Figure 65 Panel Drop Test at Three Foot Height

Figure 66 Damaged Panel Dropped From Three Feet

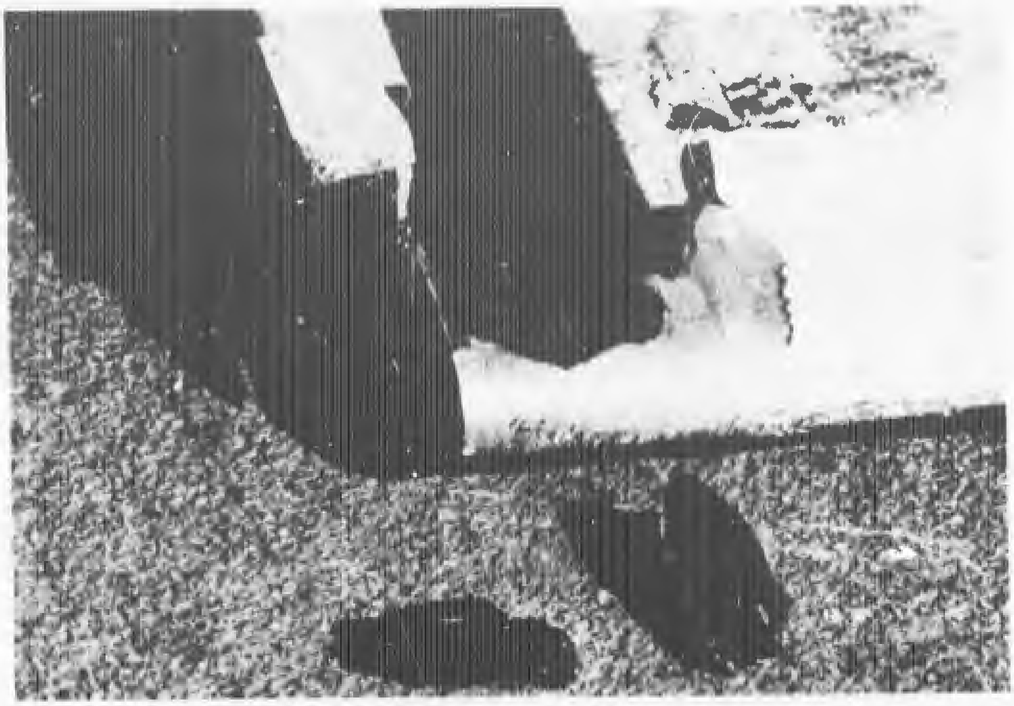


Figure 67 Damaged Panel Insert When Dropped From Six Foot Height

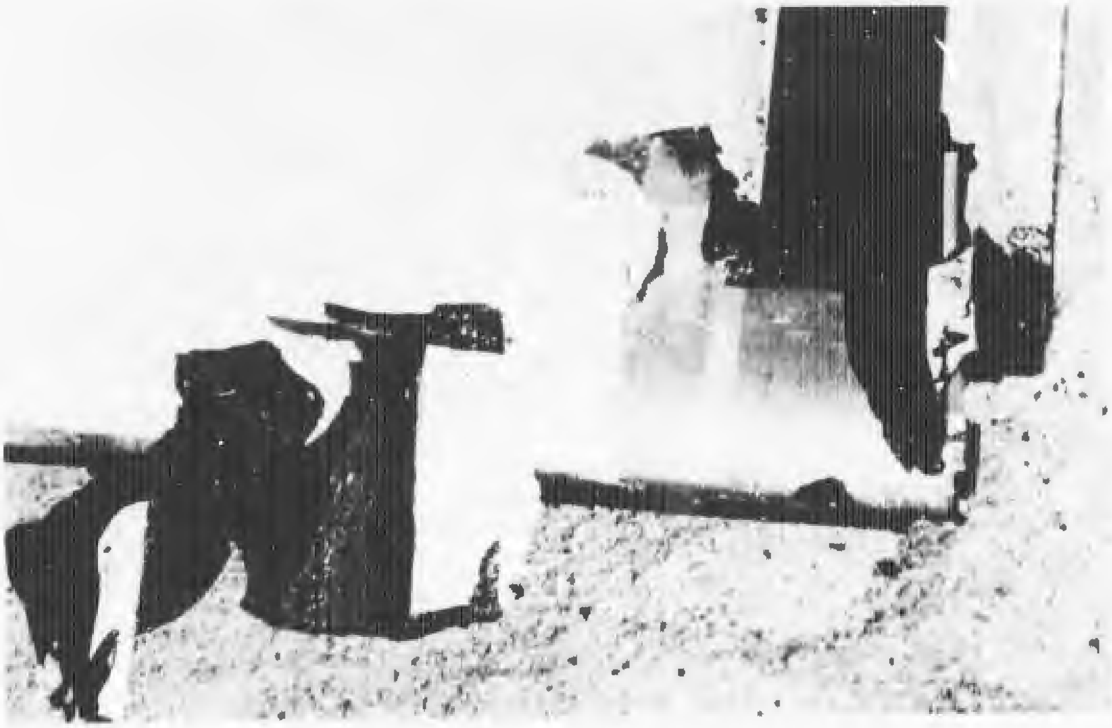


Figure 68 Damaged Panel Insert When Dropped From Six Foot Height

six-foot height. These particular panels had been used in the shelter. One can observe the sand and grit that accumulated in the insert and the buildup that subsequently developed. The condition of the inserts after being dropped from the six-foot height did not make them unusable; in fact, they were put back into the shelter without any noticeable difference. Figure 69 is a photograph of a puncture in the skin of the panel and the honeycomb core exposed. This puncture came as a result of one of the drop tests from the three-foot height. The panel was held

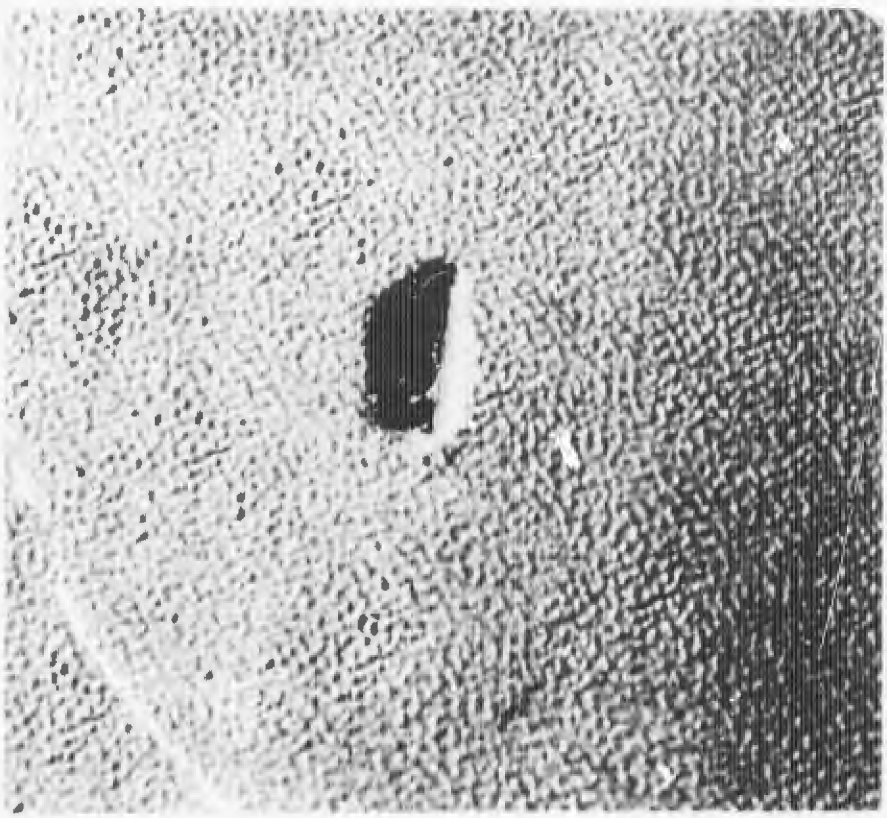


Figure 69 Puncture (approx ½ in) in Panel Skin With Honeycomb Core Exposed

in the vertical position for the drop and when it impacted the ground on the edge it fell over on a small rock. The weight of the panel falling on the rock on the concrete surface penetrated the .017 inch thick aluminum skin without any difficulty. This was noticeable throughout the test phase of dropping panels on the concrete. A surface puncture such as this would allow the water to migrate inside the panel and render it useless in a short time. If the panels were handled carefully through the erection process, no damage resulted. Under field conditions, one can assume somewhat rougher handling than the panels esperienced during the test. The thin aluminum skin, the edge members and panel inserts would most likely undergo a great deal of damage during the life of a shelter.

6. Arch Removal Test. Due to the assembly procedures of the arch, that being to install all of the panels from one side of the building, the repair of the damaged panel could then require the panels in that particular arch to be removed to reach the damaged panel. Assuming that a panel on the lower portion of the building may be damaged on the opposite side of the shelter where the panels were initially installed, it would then require removing most of, if not all, of the panels in that arch. For the purpose of this test, the arch selected was the row of panels between the fourth and fifth arch beam, the center location of the building.

The time required to remove the panels was 6 manhours, approximately the same time it took to install the panels in the arch, at that point (Figure 70). The removal of the panels was accomplished without

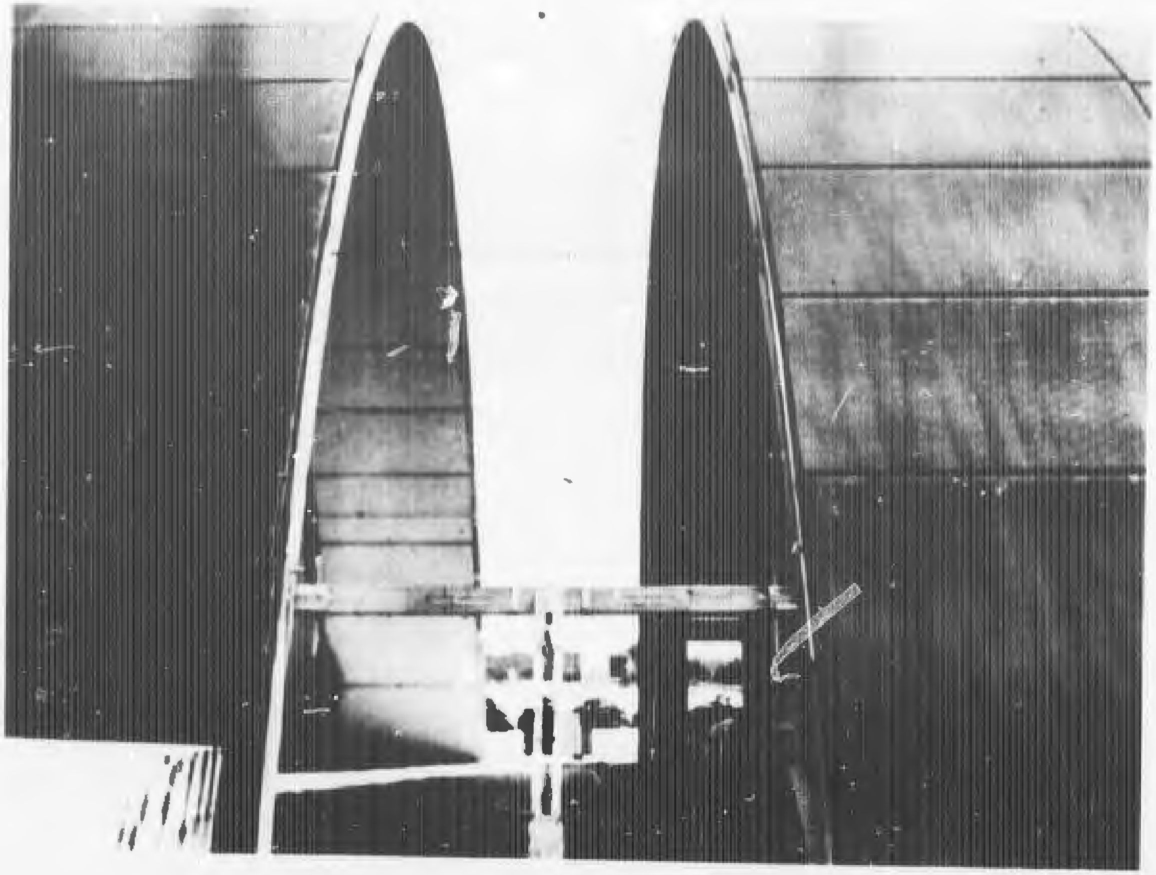


Figure 70 Panels Removed Between Fourth and Fifth Arch Beam

much difficulty with the exception that the foot of the T-bar installation winch kept jumping off of the bolts that were prepositioned on the base channel. This problem had not been encountered before during the installation because the force exerted through the winch pushed the panels upward and forced the foot down onto the base channel. In removing the panels, the force was reversed and tension was exerted in the cable to pull the panels out of the arch beam, and creating a lifting action to pull to foot off the base channel. This was easily corrected by installing bolts that could be tightened down to

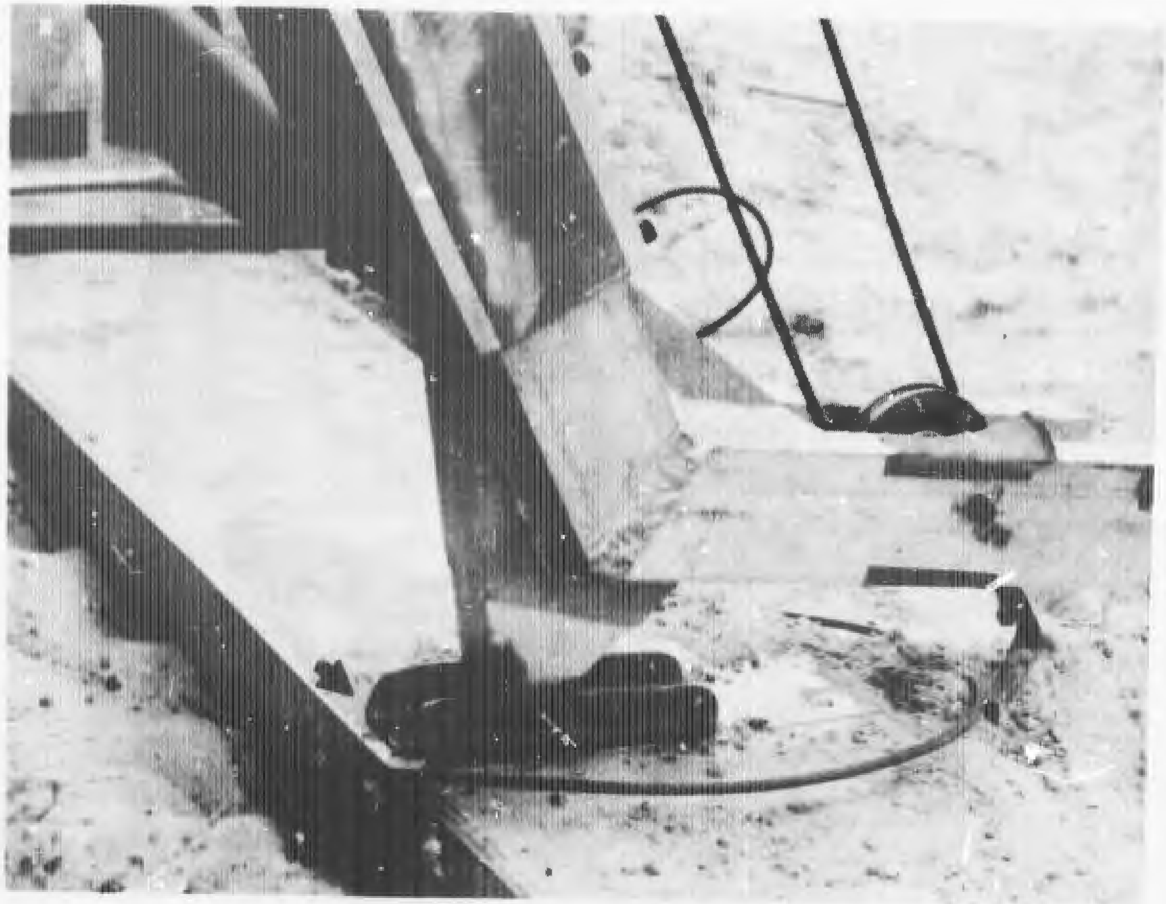


Figure 71 Base Attachment Raised During Panel Removal

hold the foot securely on the base channel (Figure 71). After all the panels were removed, it was observed that there was no appreciable damage but there was a build up of sand in the panel inserts that rode over the arch beam tracks. The sand was mixed with the silicone lubricant and had become almost a greasy paste-like substance. These deposits apparently built up over a 3 month period, since the time that the building was first erected (Figure 72).

Figure 72 Panel Inserts After Removal From Arch Beam

Before the panels were reinserted in the arch beams, all the sand and lubricant accumulation was cleaned from the panel inserts. Two days lapsed since the panel removal before the reinstallation commenced. Only three panels could be hand inserted between the arch beams and the panel installation winch was used during the remainder of the installation. The time required to reinstall all 23 panels was 12.2 man hours, which was almost double the normal time required to install the panels on a typical section. It was concluded that during the two days additional settlement had occurred on the base channel. Reinstallation of the panels between these two arch beams was in effect installing

panels between two separate structures. As the panels were pushed up over the arch, they had the effect of joining two buildings together to make one again. The differential settlement caused the uneveness between the two arch beams, thereby creating a more difficult task in installing the panels. One of the panels, number 18, buckled somewhat during the panel installation procedure. It was visible that the metal skin had partially separated from the honeycomb core, caused by the extreme pressure required to force the panel over the arch. This was the only panel that incurred any damage.

7. Repair Kit Test. Two types of repair kits were furnished with the shelter. The first being pieces of material the same as the fabric door cover and a cement, the second being rectangular pieces of the aluminum skin (the same as was used in the panel fabrication) and epoxy containers with filler and binder.

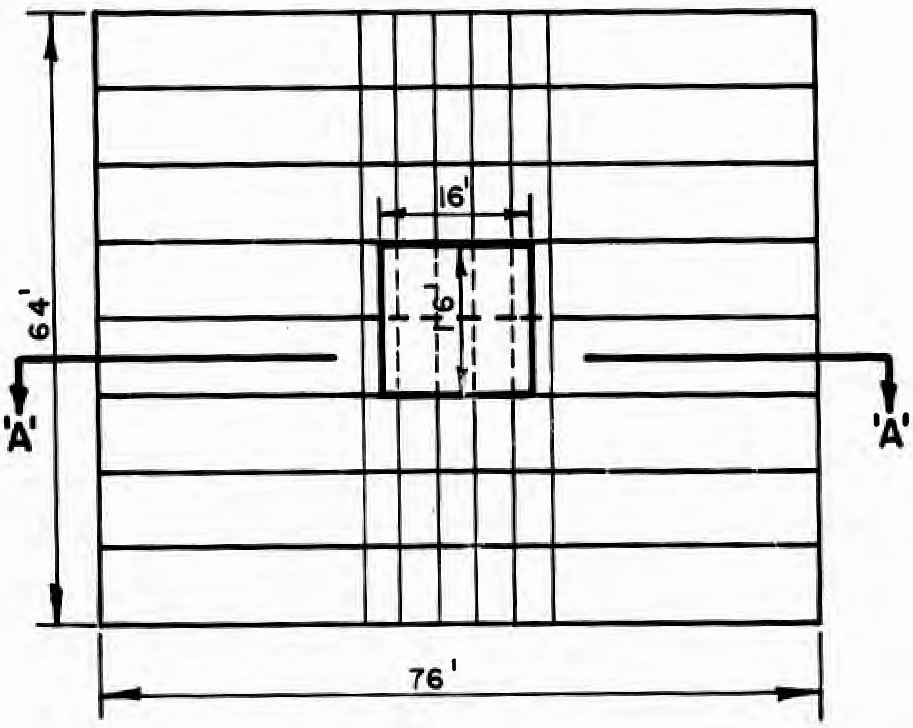
(a) Fabric Repair Kit. Several patches were installed on the fabric door to observe the durability and effectiveness of the repair methods. Some of the small holes that had been cut by the grommet screws were used to test the repair. The surface of the fabric door was coated with the cement as was the patch. Pressure was applied by hand to secure the patch to the fabric door. Initially, the patch adhered to the fabric door very well, but as time progressed in conjunction with the opening and closing of the door, the corners of the patch were observed to come loose. The center of the patches held well in most cases and it is felt that if equal pressure had been applied over the whole patch when it was initially installed, the

corners might not have separated. Ideally, patches should be applied with the fabric door in a hroizontal position. It, of course, would not be practical to lower the fabric door everytime a small puncture occurred. Therefore, the patch kit was suitable for the purpose intended and if patches loosened over an extended time period another patch could be quickly applied. Large repairs would be somewhat more difficult, but it is not probable that large rips would occur in the fabric door because of the strength of the material. Several holes did appear in the fabric door which were caused mostly by equipment or hand tools puncturing the fabric but no tearing resulted in any case.

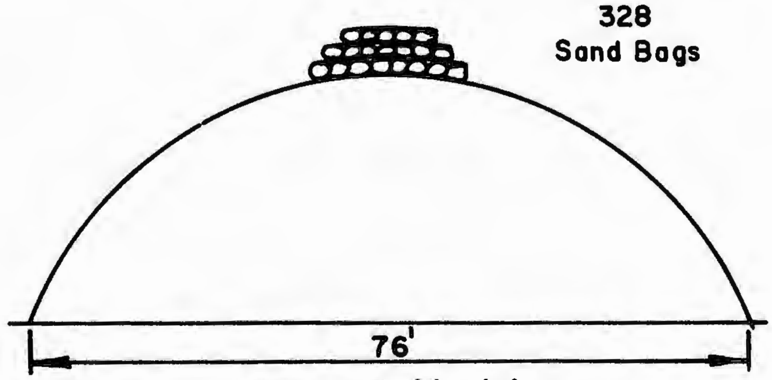
(b) Panel Repair Kit. Several repairs were effected on different panels, some while the panel was installed in the arch and others undertaken on a flat horizontal surface. Repairs were accomplished first by cleaning the puncture on the face sheet of the damaged panel. Then the epoxy filler was poured into the void and some epoxy binder painted onto the surrounding area. A rectangular patch was installed over the damaged area and kept under pressure until it was securely bonded to the panel. The repair technique worked well while the repair was accomplished on the ground, but it was difficult to apply the epoxy to a damaged area while the panel was installed in an arch except on the top of the shelter. The viscosity of the epoxy was such that it would run somewhat, causing voids under the face sheet after it was put in place. Tests were also conducted on panel repairs by using the epoxy filler without the aluminum face sheet. This method worked equally well as with the face sheet and took less time, Numerous

observations were made over an extended period of time on both repair techniques. No degradation in either method of repair was noted over a three month period.

8. Snowload Test (Unstable Area). The statement of work for the building required that it be capable of supporting 50 lbs per square foot snowload. In order to test this capability, a load test was devised which consisted of placing sandbags over a sixteen foot square area in the center of the building between arch number 4 and 6. The loading of the building with sandbags was accomplished by first placing 186 sandbags over the 256 square foot area and then a second lift of 96 sandbags and a third lift of 46 sandbags (Figure 73). The configuration was designed to simulate a snow load that would accumulate on the top of the building in a conical fashion. Sandbags could not be placed beyond 8 ft from that center line because of the curvature of the building. The 16 ft horizontal distance was determined as being adequate to accomplish the test. Each sandbag was filled with approximately 30 lbs of sand. The total load on the building was approximately 9,800 lbs, or about 38 lbs per square foot. After the first lift or 21 lbs per square foot loading, deflections were measured both inside and outside the shelter. The deflection at the center was 4½ inches and 3/4 inch at the outer edge of the load area. The second and third lift of sandbags were then put in place and deflections were again measured on the shelter (Figures 74, 75 and Table V). Measurements were taken on the top of the shelter with the string line tied to the outer ends of the building and deflections recorded from the top of the panels to the string line at the points



LOAD TEST: UNSTABLE AREA



SECTION 'A'-'A'

Figure 73 Layout of Simulated Snowload Test

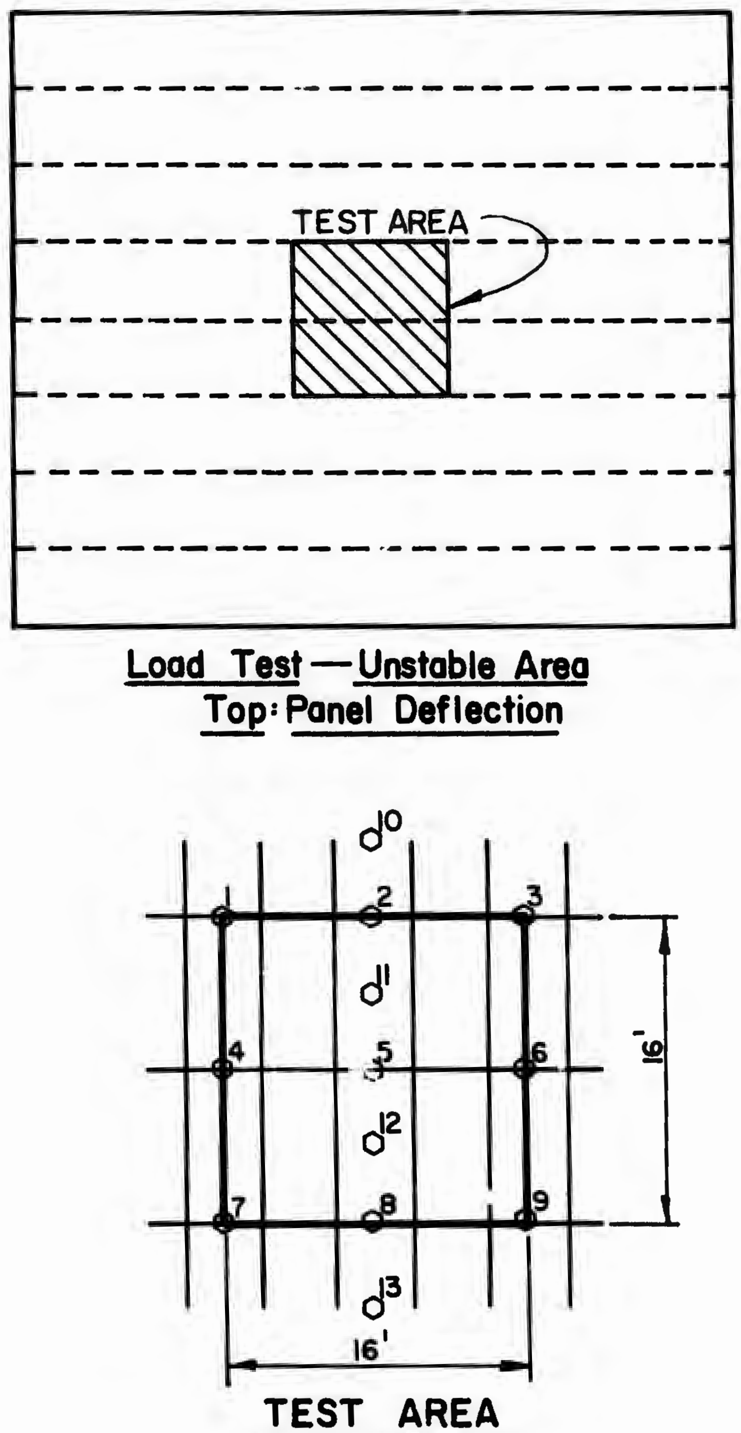


Figure 74 Measurement Point on Top of Shelter for Panel Deflections

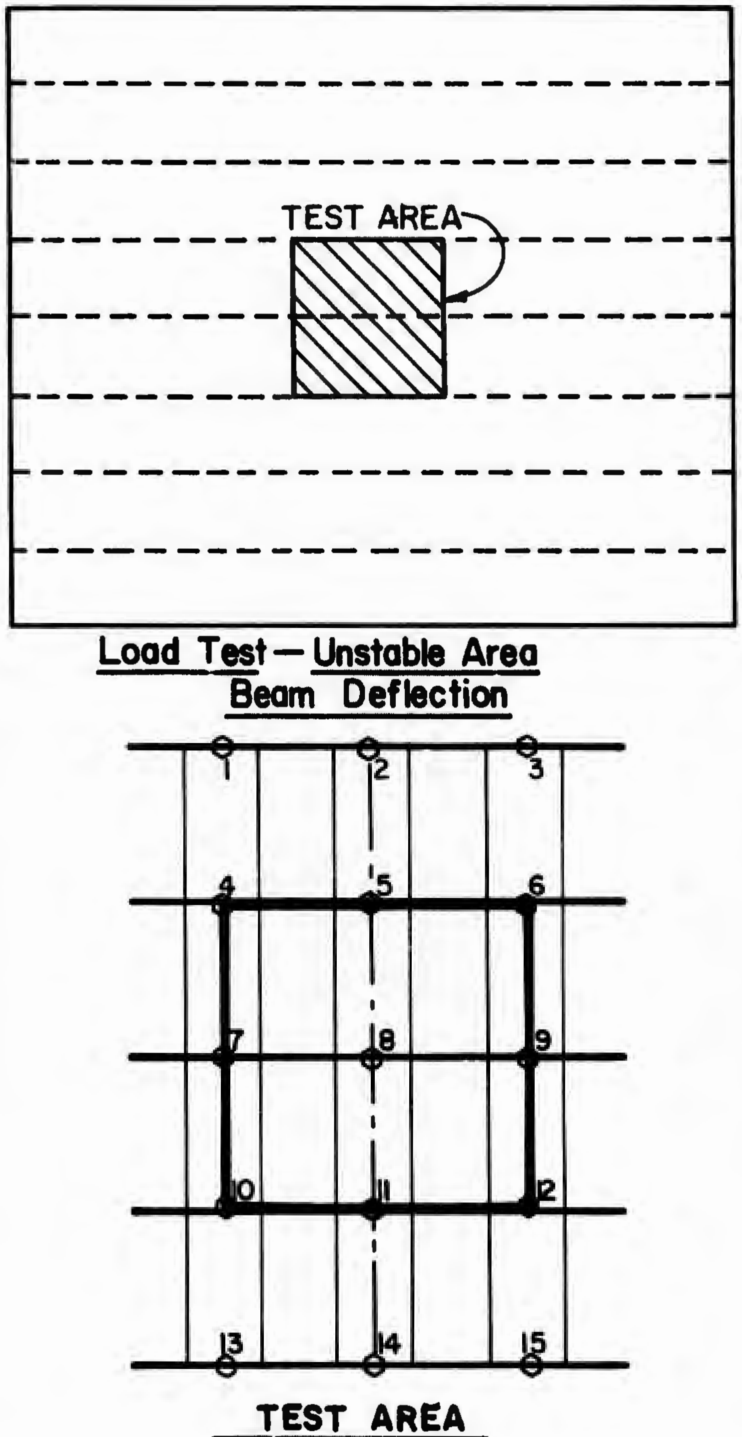


Figure 75 Measurement Points Inside the Shelter for Beam Deflectors

indicated in Figure 74. The weight of the personnel taking the measurements was not taken into account during the test. Measurements were also taken inside the shelter by extending a sixteen foot 2 x 4 from the bottom of the fifth arch beam and extending it under the third arch beam and fourth arch beam, and then the 6th and 7th arch beam, and deflections recorded. Tabulation of measurements for the panels and beams are shown in Table V. Strain gauges, were also installed on the 5th arch beam to record data during the test. Figure 76 shows the

TABLE V

Simulated Snowload Deflections

MEASUREMENT LOCATION	PANEL DEFLECTION (inches)	BEAM DEFLECTIONS (inches)
1	5 3/4	2
2	8 7/8	3
3	5 1/8	2 1/8
4	11 7/8	4 1/2
5	14 1/8	7 3/8
6	11 1/8	4 3/8
7	6 3/4	10 7/8
8	12 7/8	13 1/2
9	5 3/4	10 3/4
10	3 1/8	4 3/4
11	12 1/8	7 3/4
12	12 7/8	4 1/2
13	4 1/8	2 3/8
14		2 7/8
15		2 1/2

Figure 76 Shelter With Sandbag Load

shelter with the sandbags in place. It was somewhat surpising to see the shelter absorb as much deflection without any apparent failure. Figure 77 shows the cente- segment of the 5th arch beam, the area under the heaviest load. The weight of the sandbags had caused the beam to deflect to such a degree that ½ inch space occurred where the bayonet slotted into the preceeding beam. Before the loading of the sandbags, the joint had no separation in the area. It was also observed that the erection pins at this particular joint became oval, rather than their original round shape. Figure 78 is

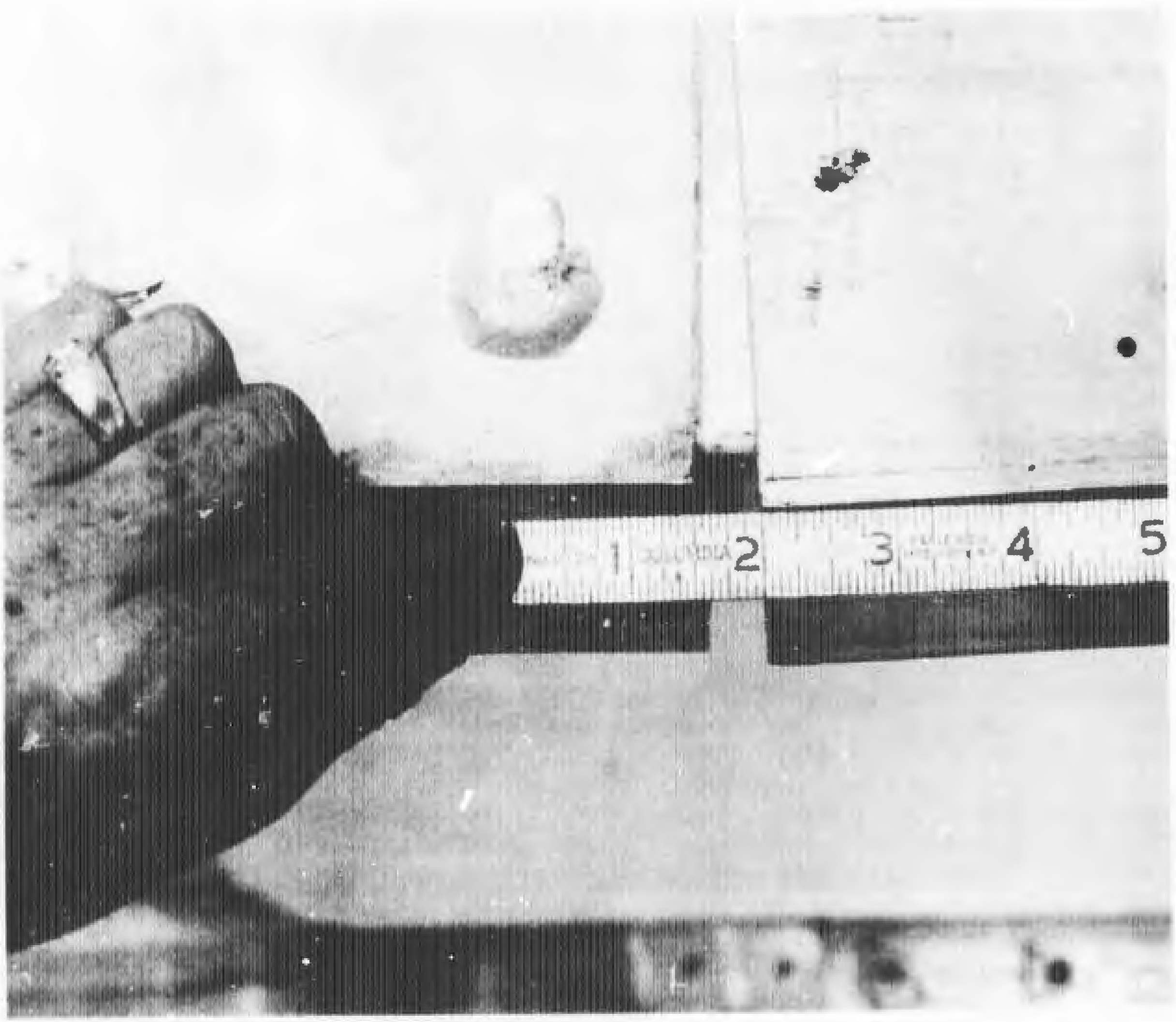


Figure 77 Joint at Center Arch Beam

Figure 78 View From Fabric Door End of the Shelter With Sandbag Load

an end view of the shelter illustrating how the test area deflected. The top of the second layer of sandbags was almost level with the elevation of the panel at the end of the shelter.

After all the deflection measurements were recorded, the sandbags were unloaded from the shelter and measurements were again taken to observe if any permanent deformation had occurred. The center segment of the fifth arch beam showed a deflection of 4½" from the original position. The outer edge, 8 ft from the center line had retained a deflection of 1". The center of the 4th and 6th arch beam showed a deflection of approximately 2 inches. No apparent structural damage occurred, but the panels between the 4th and 5th beams and the 5th and 6th beams were observed to have somewhat of a bow after the sandbags were unloaded. One of the L-shaped locking bolts for the panel tensioning bars broke in the base channel as a result of the load test. The loaded panels retained a deflection after the disassembly of the shelter. The panels were turned on the reverse side of the deflection and supported at each end with 4 x 4's. Sandbags were placed on the panel to load it in the opposite direction and within one day the panels had regained their original shape.

SECTION V

SHELTER DISASSEMBLY

The disassembly of the shelter took place in the latter part of June 1974. The shelter had been erected for approximately 6½ months. During that time period the various test described in Section IV were conducted. Also, the personnel that were assigned to disassembly of the shelter had become familiar with the components of the shelter and their operation.

The first task that was undertaken on the disassembly was the removal of the panels between the 8th and 9th arch. A 3/4 inch drill was used on the panel winch, as had been used in the erection sequence. After the first panels were removed with the drill the remaining 10 panels could be removed by hand. The panels had passed over the center line of the building at that point and very little resistance was encountered in removing them. The total time for this task was four manhours, about half of what was required to install the panels in this particular arch. Before the metal end wall could be lowered, the keeper pin that holds the cable that runs the length of the building had to be removed from the 9th arch beam with a center punch because of corrosion. In removing the pin, it was damaged beyond repair. This discontinuity of the materials and the exposure of the steel pin to the 6½ months of the salt and sand had caused it to become very corroded. After the pin was removed, the door was lowered onto prepositioned jacks without any problem. During the disassembly of the metal door, corrosion again became a factor in the piano hinges that held the door panels between

the vertical beams. Hammers and visegrips were required to remove these pins. These minor problems were quickly overcome and the total disassembly time for the metal end wall was 25 man hours, a little more than half of the initial assembly time.

The disassembly of the shelter progressed extremely well up to the point where the load test was conducted.

The removal of the panels between the 6th and 5th arch was a great deal more difficult than the panel removal of the previous two archs. This could be directly attributed to the distortion of the panels as a result of the sandbag loading. A crane was used to raise 5th arch beam (the beam that had been subjected to the heaviest load) from inside the shelter. After some force was exerted on the beam, the panels were removed with minor difficulty. Inspection of the panels in this arch revealed that 11 of the panels had undergone minor damage at the panel inserts where they ride on the arch beam tracks. Only three of the panels were able to be removed by hand, whereas in the two previous archs, 12 to 13 of the panels could be removed by hand. The disassembly of the 5th arch beam caused some difficulty at the three center sections, particularly on the center beam. The sandbag load had distorted the erection pins to the point where they were oval. Removal of these two pins were very difficult and caused some delay.

The remainder of the disassembly proceeded without any problems. The times recorded for each of the phases are shown in Table VI. The overall disassembly of the shelter took approximately 100 man hours less than the erection time. This time did not include repacking the components.

TABLE VI

Shelter Disassembly Times

TASK		MANHOURS
1.	Remove Panel between 9th and 8th Arch	4
2.	Lower Metal End Wall	1
3.	Disassemble Metal End Wall	25
4.	Remove Panel between 8th and 7th Arch	1.9
5.	Lower 8th Arch Beam and Disassemble	1.8
6.	Remove Panels between 7th and 6th Arch Beams	2
	6th and 5th Arch Beams	6
	5th and 4th Arch Beams	5.25
	4th and 3rd Arch Beams	1.3
	3rd and 2nd Arch Beams	1.3
	2nd and 1st Arch Beams	1.3
7.	Lower 7th Arch Beam and Disassemble	1
	6th Arch Beam and Disassemble	.66
	5th Arch Beam and Disassemble	1.5
	4th Arch Beam and Disassemble	.66
	3rd Arch Beam and Disassemble	.66
	2nd Arch Beam and Disassemble	.66
8.	Remove Side Entry	1.5
9.	Lower Fabric Door	1.2
10.	Disassemble Fabric Door and Arch Beam	10
11.	Disassemble Base Rails	2
12.	Dissassemble A-Frame Gantry and Winch System on Containers	4
13.	Repallet Panels and Arch Beams	21.2
	TOTAL:	95.89

The contributing factors for the reduced time were primarily the experience that the personnel had acquired handling the various components of the building, and the time required for the removal of the panels between the beams, with the exception of the panels of arch 4 and 5. The initial extraction of the panels presented the same problem as the installation, that being, when the puller was attached to the center of the panel, it caused a similar deflection in the panels. After the panels had reached the center point, the remainder of the panels could be removed by hand, and went extremely fast.

The marked reduction in the disassembly time of both the fabric and metal end walls was mainly due to experience. The fact that the piano hinge pins were being withdrawn in the metal door enabled them to be extracted all the way rather than being forced into the hinge inch by inch, saving a great deal of time.

The fabric door disassembly went quite fast. The major time-consuming facet was the unfastening of the grommets.

SECTION VI

SECOND SHELTER ERECTION AND TESTING

1. General. After completion of the first phase of testing, a stablized area was prepared to re-erect the shelter to test its capabilities on a level site rather than on the uncompacted soil. The area was prepared with crushed shell mixed with sand and rolled to provide a firm base. The primary purpose of the stabilized area test was to observe if there were any differences in the panel installation and the operation of the end closures, particularly the metal end wall. When the erection site was adequately prepared, assembly of the shelter began on 29 July 1974.

2. Shelter Erection. After location and assembly of the base rails, another anchoring system was installed for a comparison with the anchoring system of the first erection. The anchor system for the first erection took approximately 75 man hours, which was considered too time consuming. The Bare Base anchoring system, the 4 inch arrowhead anchors with attached cable, was utilized. A cable was attached to the arrow head anchor on the inside of each section of the base channel and installed four feet below the surface. The second anchor was then driven into the ground with a jackhammer to approximately the same depth, thereby creating an inverted U-shaped cable anchored on each section of the base channel. It was anticipated that this anchoring system would suffice for the wind load the shelter might undergo during erection and also reduced the spreading of the base channel previously experienced. After the base rail was anchored and leveling plates were installed for

the container, the erection winch was assembled. A modification to the A-frame gantry was made by drilling the holes for the previously-used bolts and installing lock pins in their place. This allowed for a much easier and faster assembly of the A-frame.

After the assembly of the first arch beam and the fabric door on the ground, the winches were used to pull the fabric door to the vertical position. As the winching progressed, the problem of the end of the base channel raising off the ground was still prevalent. The winching operation was stopped and the door was lowered back to the ground and more arrowhead anchors were attached at the end of the base rail to hold it firmly in place. It was also discovered that the weight of the fabric door was moving the base channel further apart. This problem was not as prevalent in the first erection because the base channels embedded themselves into the sand making the movement not as noticeable. On the stablized surface, the base channels did not embed themselves into the compacted soil and therefore started to slide across the top of the surface. To correct this, three ½ inch steel cables were attached between the base rails on each of the first three base channels. After the cables were installed, the raising of the fabric end wall continued with no further problems. The distance between the base rails remained constant and very little movement was observed in the base rial lifting off the ground. The times for each task during the second erection of the shelter are shown in Table VII.

TABLE VII

Second Erection Time

NO.	TASKS	TIME (MH)
1	Locate base rails layout base rails, anchor plates and anchor.	25
2	Assemble A-frame and erection winch on container.	6
3	Assemble first arch beam and fabric door.	10
4	Install cables between base channels.	6
5	Assemble second arch beam.	1.5
6	Raise second arch beam.	.3
7	Install panels between 1st and 2nd arch beam.	10
8	Assemble 3rd arch beam.	1
	4th arch beam	1
	5th arch beam	1
	6th arch beam	1
	7th arch beam	1
	8th arch beam	1
9	Raise arch beam and install panels between:	
	2nd and 3rd archs	2.5
	3rd and 4th archs	3
	4th and 5th archs	2.5
	5th and 6th archs	2.0
	6th and 7th archs	3.0
	7th and 8th archs	5.5
10	Install side entry door	2
11	Assemble 9th arch beam and metal door and track.	40

(Table VII, continued)

12	Raise 9th arch and metal door.	3
13	Install panel between 8th and 9th arch.	7.5
14	Install personnel doors (metal end wall).	2.0
15	Install personnel doors (fabric end wall).	4.0
	TOTAL:	141.8

The installation of the panels between the first and second arch beam took approximately 10 man hours. The degree of difficutly of installing the panels between the first and second arch beam appeared to be an inherent time consuming task, primarily due to the weight of the first arch beam with the fabric door and the flexibility of the second arch beam.

The remainder of the erection sequence went very well until the panels were installed between the 8th and 9th arch. The times recorded for the panel installation between the 2nd and 8th arch was much better than those recorded during the first erection. The panel installation winch required repair several times during the second erection, but those times are not included in the recorded times. During the panel installation between the 7th and 8th arch, the cable on the panel winch broke twice and required replacement. The time recorded includes replacing two cables on the winch.

The assembly of the metal end wall doors went somewhat faster during the second erection than the first erection. The recurring problem of installing the pin into the piano hinges that secured the panels to the vertical beams caused the most difficulty. Some of the

pins had become distorted from use and some of the hinge sections were out of line from handling. Before the erection of the metal end wall, a cable was tied between the base channels to secure it at the proper distance and additional anchors were installed along the end of the base channel to prevent movement. The erection of the metal door went very smoothly with no problems encountered. The installation of the panels between the interior arch beams was always much easier than the installation of the panels between the end walls and the preceeding arch beam. During the second erection, depending on the arch, five to eight panels were able to be installed by hand, with little difficulty. The overall time required for the second erection was 141.8 man hours, which was somewhat better than the first attempt. This time also included the installation of an anchoring system which was not recorded during the first erection.

After the erection of the facility was completed, both doors were cycled again to see if their was any noticeable improvement over the previous times that had been recorded. The times for the fabric door remained approximately the same, whereas the time for the metal door was reduced in some cases. The binding of the door was still prevalent in the upper rail. It had been thought that by erecting the building on a level area this problem would have been resolved. In some cases the door opened very well; then again, it bound in the track for no apparent reason. Average time after 5 cycles was reduced to about 12.2 min. in the opening and closing mode.

3. Load Test Stablized Area. After the first load test was completed, analysis of the deflection data indicated that the controls established to record deflections were not sufficent to provided a true picture of the actual deflections that occurred. Variance in the weight of sandbag, stacking procudure, recording deflections, measurement through the sandbags, and using the shelter as a base line to record the deflections of both inside and out contributed to the lack of accuracy during the first test.

Prior to the second test, new sandbags were utilized and each sandbag was weighed on a platform scale to insure each bag when filled weighed exactly 30 lbs (Figure 79). To insure accurate deflection measurements were obtained, strings were tied to predetermined points on the arch and the center of the panels between the arches, as shown in Figure 80. Large nuts were then tied to the bottom of the string line and left overnight to insure that all the strings were stretched in equal amounts. The following day pieces of wood were imbedded in the compacted shell and the nuts were then retied to the string at an exact 2 ft height (Figure 81).

In all, twenty one measuring stations were established in the area where the sandbags were to be loaded. Figure 82 is an expanded view of 16 x 24 ft area that was tested, and defines where the data points were established. The sandbags were loaded in such a manner that three arch beams and four rows of panels would be directly affected. Data points were also established outside this area to observe deflections with the connecting components (Figure 83). The sandbags were loaded

Figure 79 Weighing Sandbags for Load Test

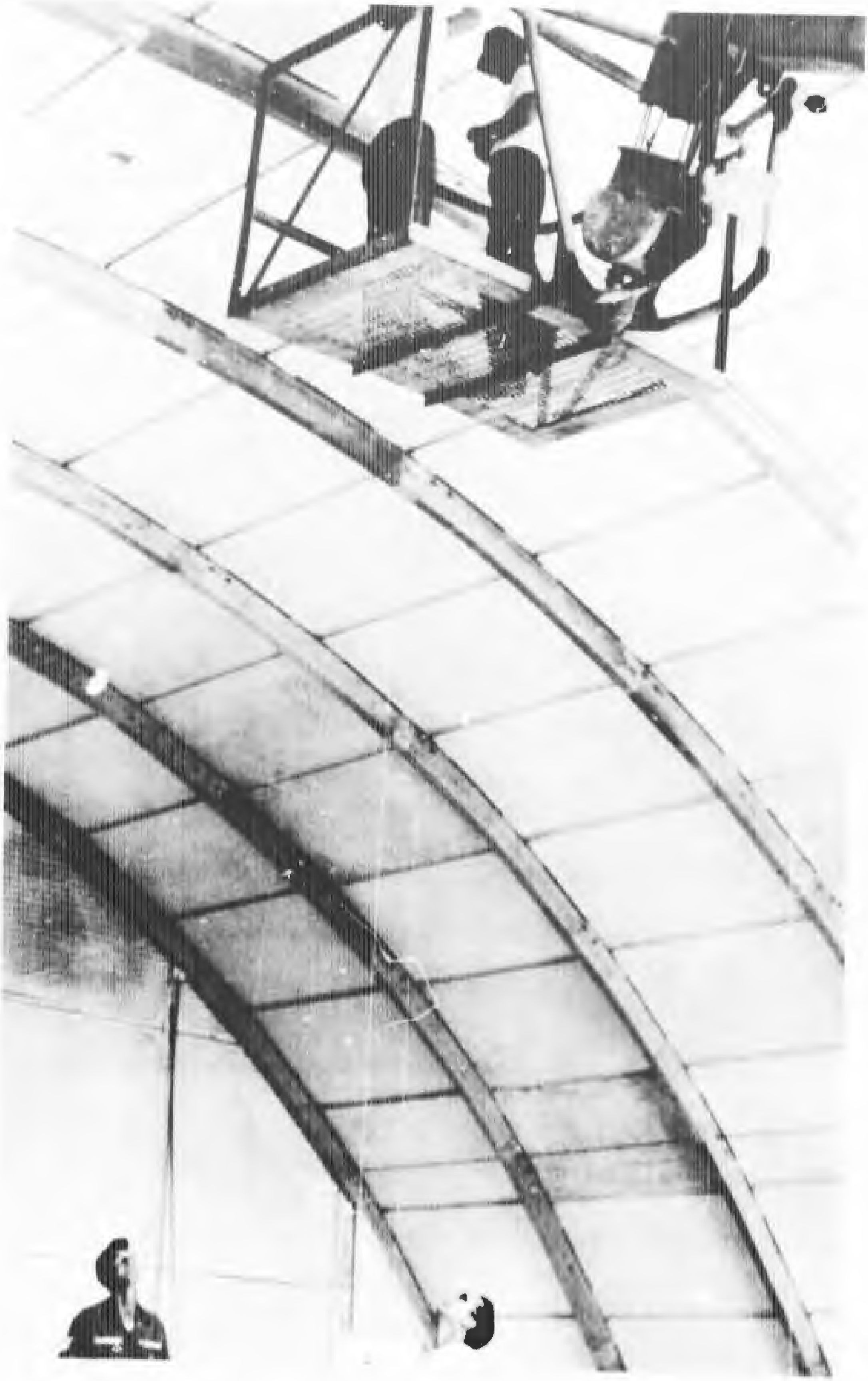


Figure 80 Attaching String Lines to Arches and Panels

Figure 81 Measuring Height of Weights Before Load Test

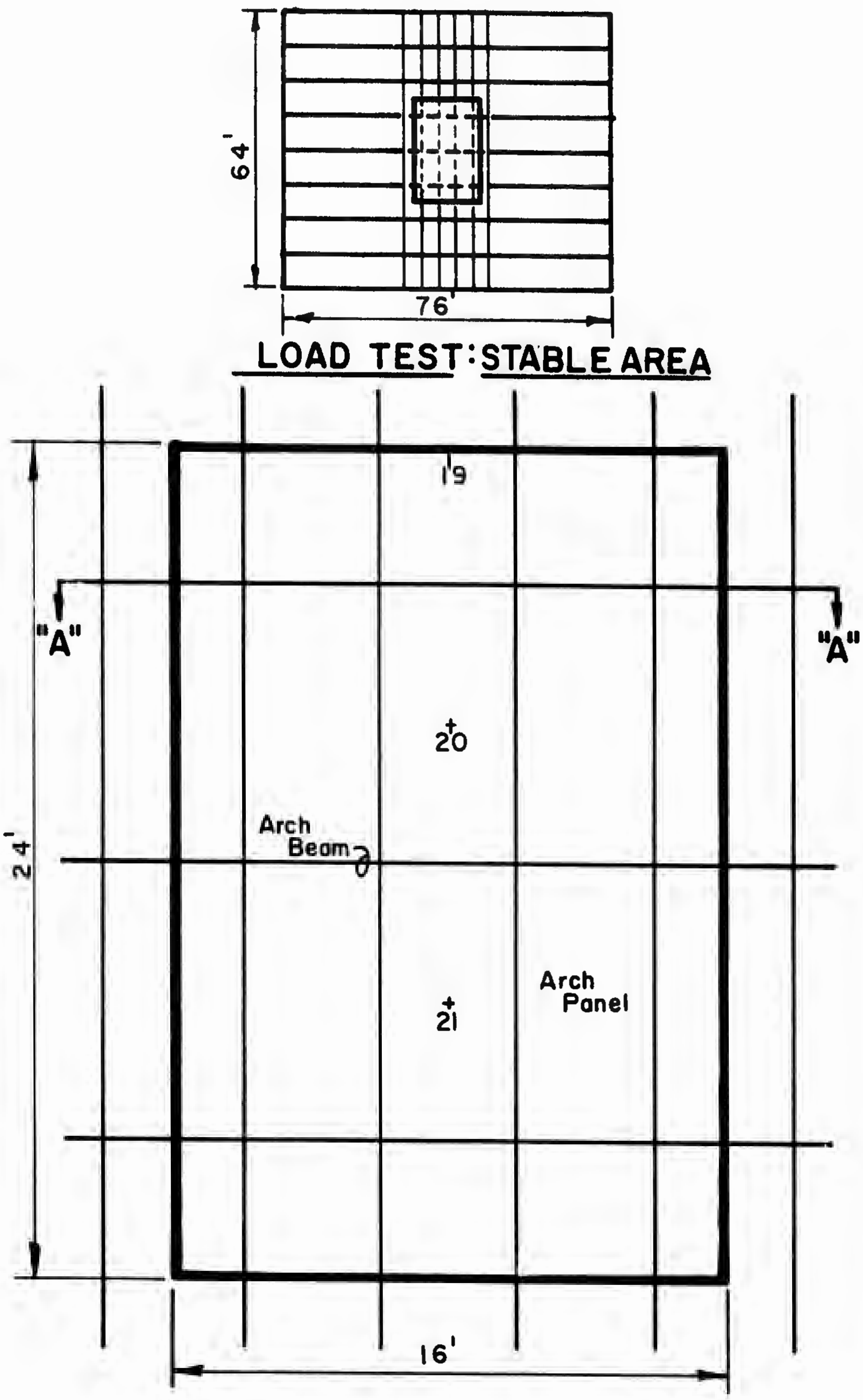
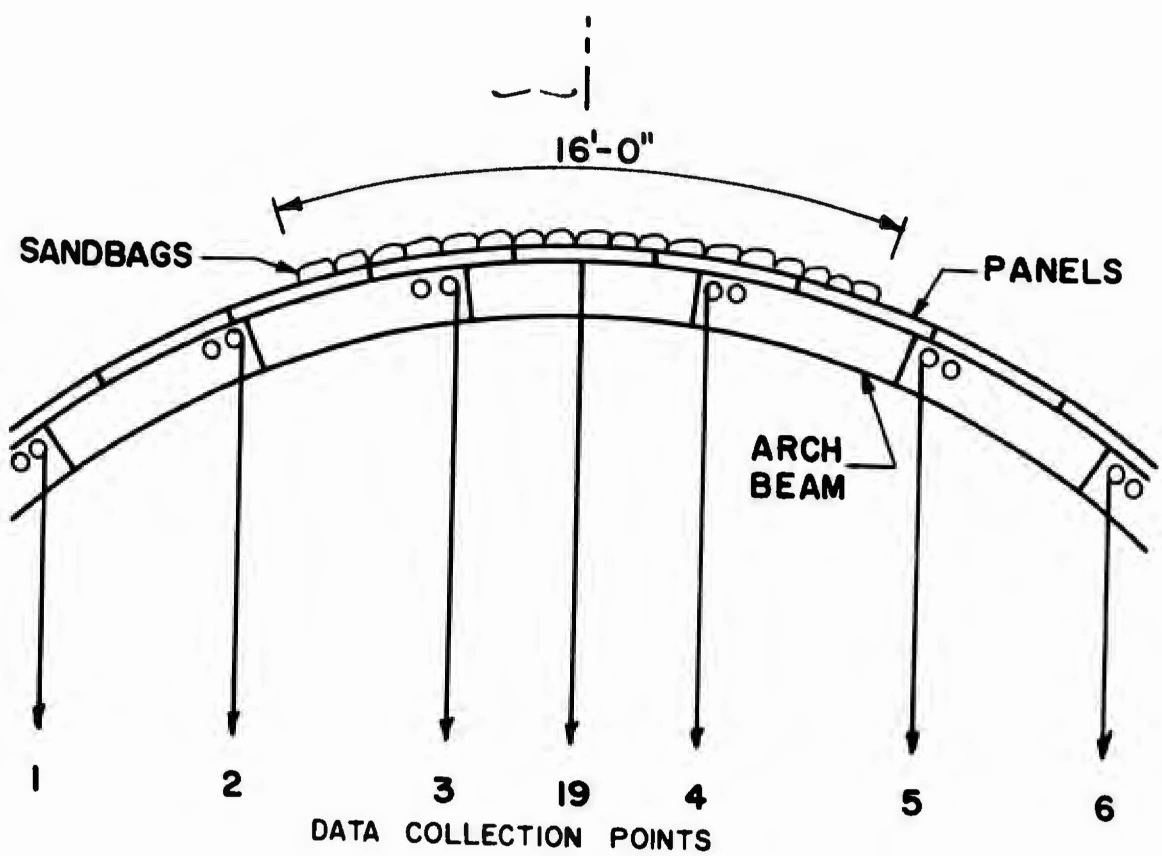


Figure 82 Area Loaded During Test with Data Collection for Panels



SECTION "A"-"A"

Figure 83 Cross Section of Test Area with Measurement Points

in three increments, the first being 10 lbs per square foot (Figure 84). Measurements were taken at all the data points after the first load was applied to the shelter. After the deflections were recorded the building was loaded to 20 lbs per square foot, and then to 30 lbs

Figure 84 Ten Pound Per Square Foot Loading

per square foot. Each sandbag was placed in a predetermined positon, to insure that the load was uniform over the entire area. Measurements were taken at 30 lbs per square foot loading (Figure 85). All personnel were removed from the top of the shelter before the measurements were recorded. As the test was being completed, a thunder storm came up in the area and the sandbags became waterlogged to a degree, thereby

Figure 85 Data Collection After Thirty Pound Per Square Foot Load

Figure 86 Overall View of Data Collection Points and Deflection Across the Arch Beams

increasing the load on the building. After the rain had subsided measurements were again taken to observe if any additional deflection had occurred. Figure 86 shows how the data collection points were located and the deflection that occurred in the building. Immediately after the measurements were taken with the saturated sandbags, the building was unloaded and measurements taken again to record the deflection that remained in the shelter. Table VIII is a summary of all the deflections that were measured during the test. Visual observation indicated that there was no permanent damage to any of the components of the shelter. The center arch beam did not undergo the deflections as in the previous test. Only a fractional amount of separation at the center joint could be observed. The erection pins remained in the round shape in all the arches. Only one panel separated at the panel-to-panel joint, whereas in the previous test four panels separated.

The bolts holding the panel tensioners in the base rail experienced no damage as a result of the loading. The shelter was left in the erected configuration for approximately two weeks before disassembly. The data collection points had been removed and no measurements were taken to observe if the shelter components had rebounded to their original configuration.

During the disassembly, the 4th, 5th and 6th arches presented no greater degree of difficulty than the other arches while dismantling the shelter. Some of the panels retained a bow directly under the sandbags, but after loading with sandbags on the reverse side they regained

TABLE VIII

Simulated Snow Load Test-Stable Area

MEASUREMENT LOCATION	10#/SF DEFLECTION (in)	20#/SF DEFLECTION (in)	30#/SF DEFLECTION (in)	AFTER RAIN DEFLECTION (in)	SANDBAGS UNLOADED DEFLECTION (in)
1	1/4	3/4	1 5/8	2	2
2	7/8	2 3/4	4 3/4	5 1/8	2 1/2
3	2 1/4	4 1/2	7 1/2	8	2 7/8
4	2 1/4	4 1/2	7 1/2	8	2 7/8
5	2 3/8	2 7/8	4 3/4	5	2
6	7/8	1 3/8	2 1/4	2 1/2	2 1/2
7	1/8	3/4	1 3/4	2 1/4	2
8	1 3/8	3	5 3/4	6 1/2	2 1/2
9	2 3/8	4 3/4	8 3/4	10 3/4	2 7/8
10	2 3/4	5	9 1/4	9 3/4	2 3/4
11	2	3 1/2	6 3/8	6 3/4	2 3/8
12	1/2	1 1/4	2 1/2	2 1/8	2 1/8
13	1/8	1/2	1 1/4	1 3/4	1
14	1	2 1/4	4 1/8	4 5/8	1 5/8
15	2	4	6 5/8	7 1/4	2 3/4
16	1 7/8	3 1/2	6 1/8	6 3/4	2

(Table VIII, continued)

17	1 3/8	2 3/4	4 5/8	5 1/8	2 1/2
18	1/2	1 1/8	1 3/4	2 1/8	2 1/8
19	1 3/4	3 3/8	5 7/8	6 1/2	3
20	3 1/2	6 1/2	11	12	4 5/8
21	3	6	10 1/2	10 1/2	4 1/2

their original shape. The arch beams and the erection pins that were subjected to the direct loading of the sandbags were inspected and no damage was observed.

4. Rain and Wind Tests. This series of tests was conducted on the stablized erection site using the wind machine with the water attachment to duplicate a rain and wind enviroment up to 60 miles per hour. Because of the constraints of the equipment, the testing was accomplished on various components of the shelter. The wind machine was positioned at different distances from each component to provide a concentrated force against the particular component and then withdrawn from the section undergoing test to obtain as much overall coverage of the area as possible. Water was supplied to the wind machine from a 5,000 gallon water tanker into a spraybar attached behind the wind machine. As described previously, the wind machine was calibrated for various readings on the odometer of the vehicle. The wind machine was allowed to operate for three to five minutes in each position. Visual observations were recorded and photographs taken.

Figure 87 shows the wind machine in operation while testing the container for water tightness. Some leakage was observed at the center rib joint of the front door and also at the left door where the erection winch was attached. As the wind machine was allowed to run, some water accumulated inside the container and began blowing back into the interior of the shelter. The rear door to the container was left open during the test to record observations inside the container.

Figure 87 Wind and Rain Test on Container

Figure 88 shows the wind machine test on the right side of the fabric door. The machine was positioned approximately 30 ft from the door when the photograph was taken. Most of the force was directed against the lower portion of the door at this point, so the wind machine was pulled another 25 ft away from the shelter in an attempt to provide coverage for half of the door. During this test phase the ground skirt was configured in two ways; first as in Figure 88, with the ground skirt pulled inside the building and sandbagged; and second with the ground skirt pulled outside the building and sandbagged. No water leakage was observed through the fabric or around any of the connection points except at the base of the door. The force of the wind and the volume of water immediately adjacent to the vertical posts where they were anchored in the ground, caused the ground skirt to be blown back somewhat and water entered freely. This was a direct horizontal exposure which would not normally be experienced. Figure 89 is a photograph from the inside of the shelter in the area where the sandbags were on the outside of the shelter to hold down the ground skirt. Water is seen to be pooling at the base of the door but the ground skirt sandbagged on the outside kept water from blowing directly into the shelter.

The personnel door and the fabric end closure were exposed to direct force from the wind machine. Figure 90 shows the water that came into the shelter during the test. The velcro strip around the door did not retain contact at the base when it was attached and all the water that impacted on the door ran straight down and into the shelter. The area

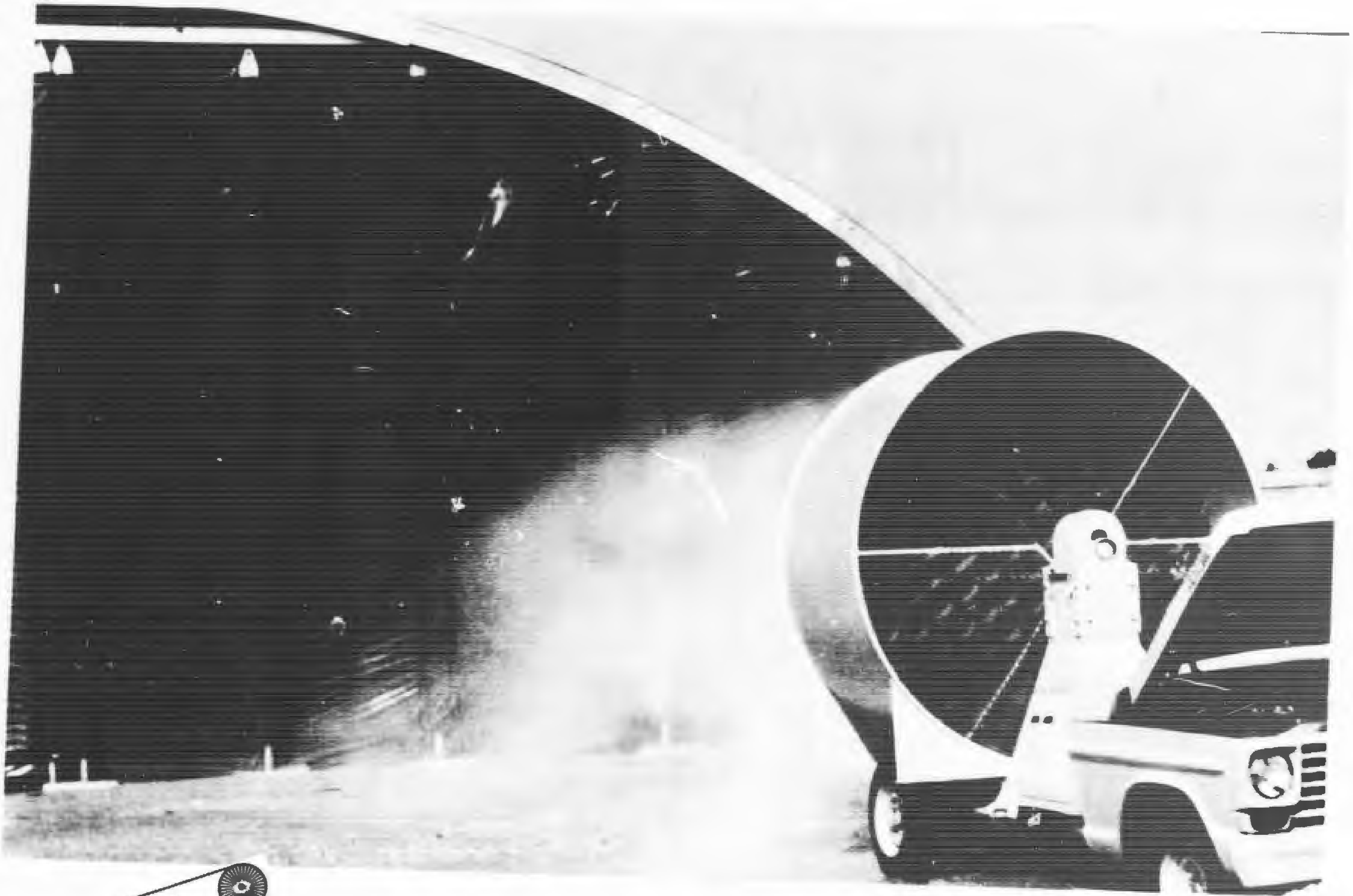


Figure 88 Wind and Rain Test on the Fabric Door

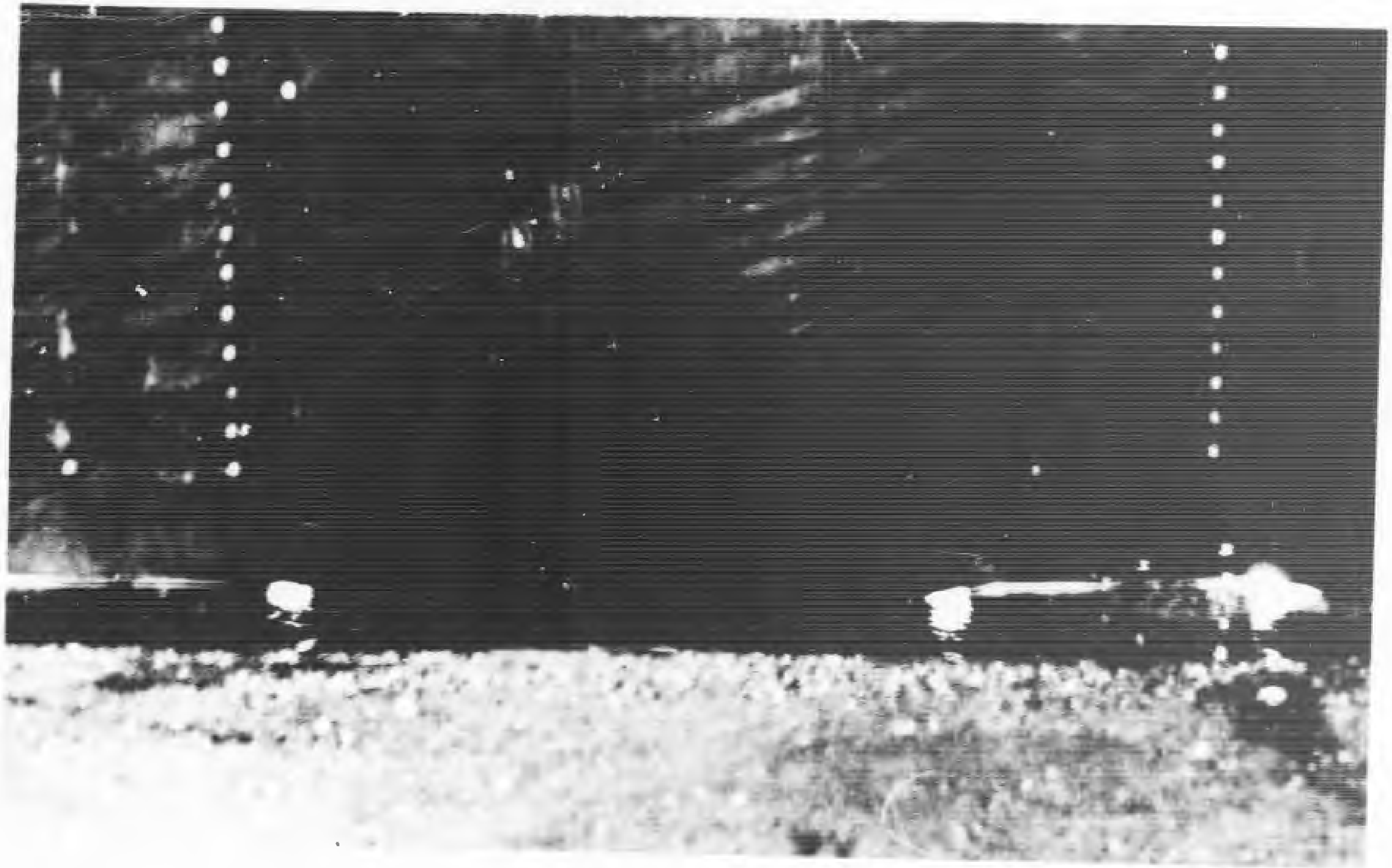


Figure 89 Water at the Base of the Fabric Door with Ground Skirt Sandbagged Outside

Figure 90 Personnel Door in Fabric End Wall During Water/Wind Test

to the left of the personnel door allowed entry of water where the vertical posts intersected the ground plate.

The side entry was also tested, in a similar manner as the fabric door. The wind machine was positioned approximately 20 ft from the door and accelerated to 60 miles per hour winds. Figure 91 shows the

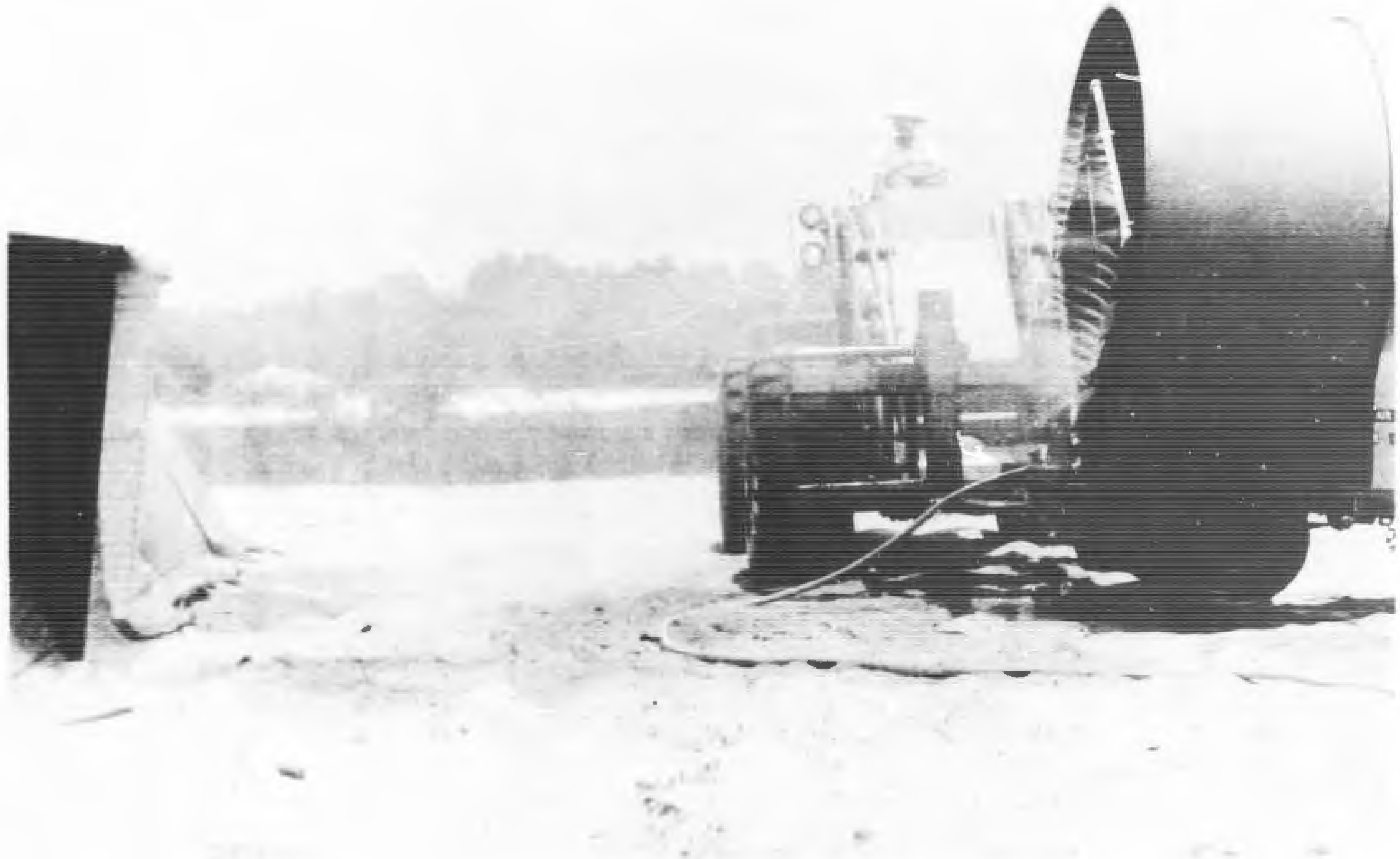


Figure 91 Rain/Wind Test on Side Entry System

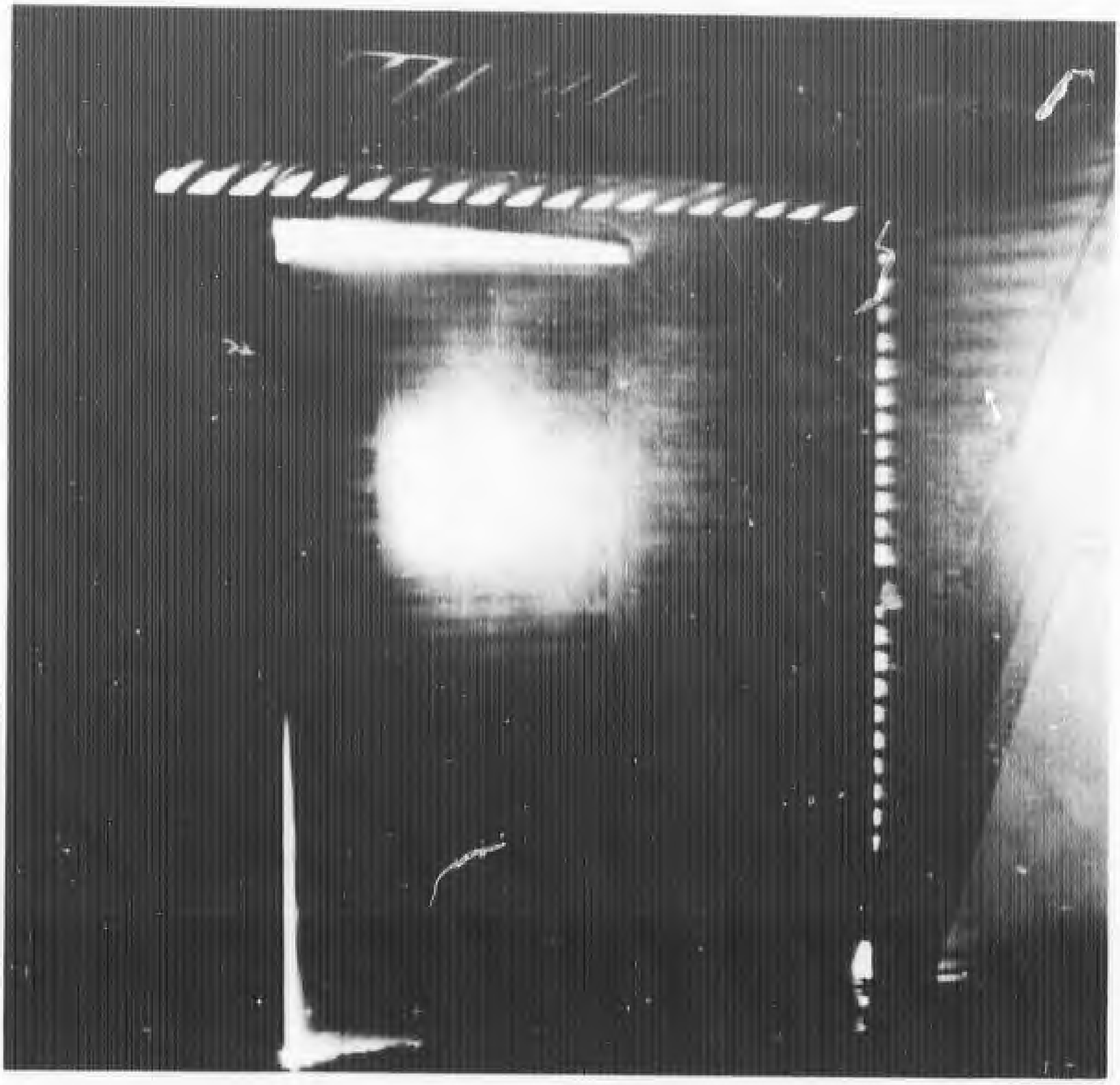


Figure 92 Water Entry on Side Door System

test being conducted. In order to get more coverage on the shelter, a forklift was used to lift the wind machine and direct the force at a higher angle to observe water impacting on the side of the shelter. Figure 92 is a photograph taken from inside the shelter during this test. Water was observed coming in all around the vertical face of the side entry where the corrugations were not flush with the framing.

Also, the flap that was located above the personnel door was blown back and water freely entered in this area. The point of connection of the side entry system to the arch beams and panel showed no leakage.

The arches and panels were also tested with the wind machine. When the wind machine was directed at a 90° angle to the center line of the shelter and the wind and water impacted straight against the side of the shelter, there was little if any leakage inside the shelter. When the wind machine was turned to impact the shelter at a 45° angle, the water did accumulate between the panels on the arch beams and water could be observed running out of the panel to beam connections all along the arch. The panels with windows were also subjected to the wind test there was no indication of any leakage, around the windows.

The last component of the building to be subjected to the rain test was the metal end wall. Figure 93 shows the sandbag arrangement for both sides of the door. The area immediately around the vertical posts where they anchor to the ground have openings which would allow the passage of water. On the left hand door with the sandbags inside the shelter the configuration appeared better. The areas at the vertical posts could be sandbagged from the inside. Figure 94 shows the wind machine in operation against the metal end wall. The ropes being blown around are the ropes used for opening and closing the door. In an actual situation they would be secured but during the test they were left to blow freely to see the effect on the door. The area that had the sandbags placed on the inside of the shelter was subject to most of the leakage. When the wind caught the ground skirt, it blew the sandbags

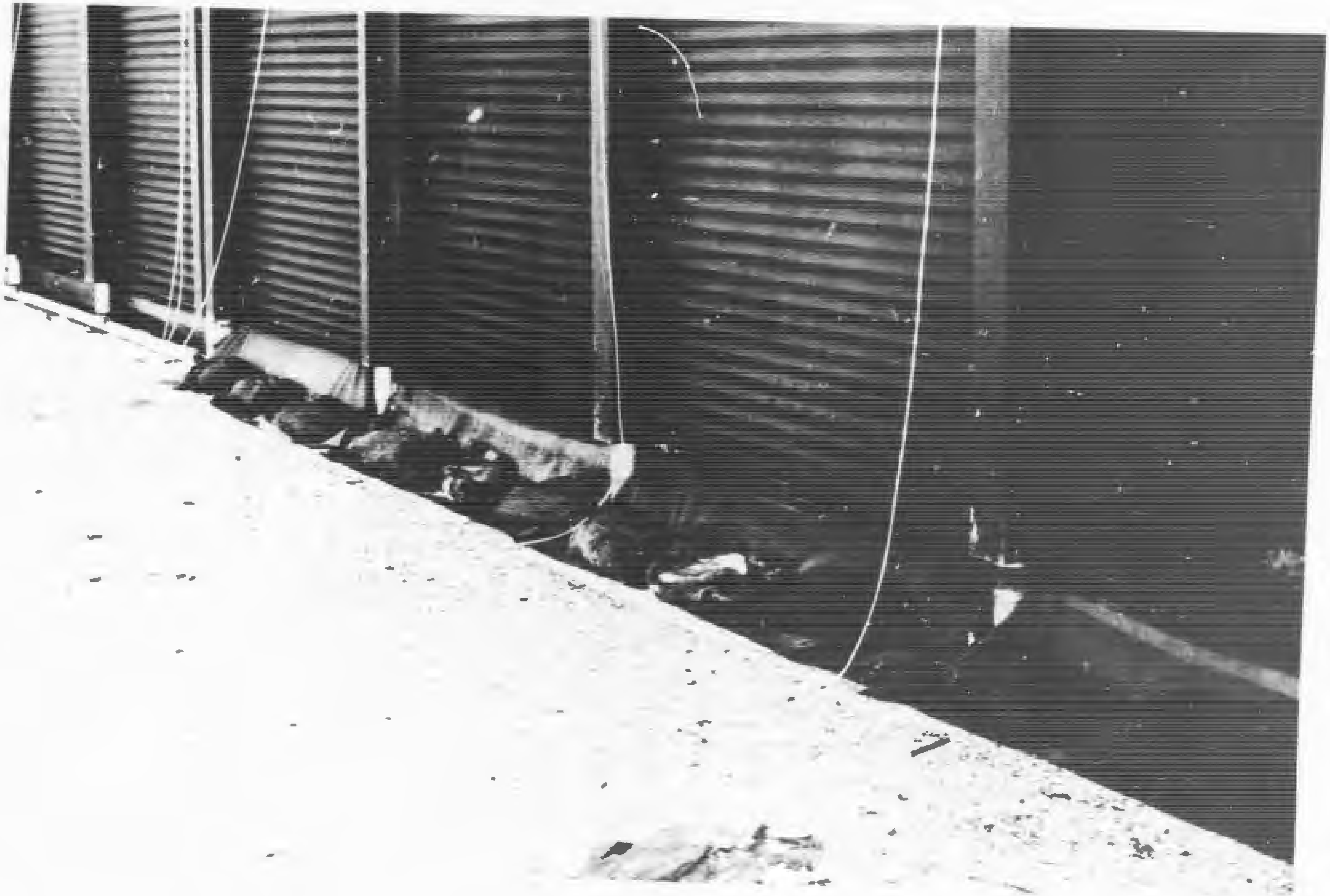


Figure 93 Metal Doors with Sandbags on Ground Skirt Prior to Wind/Water Test

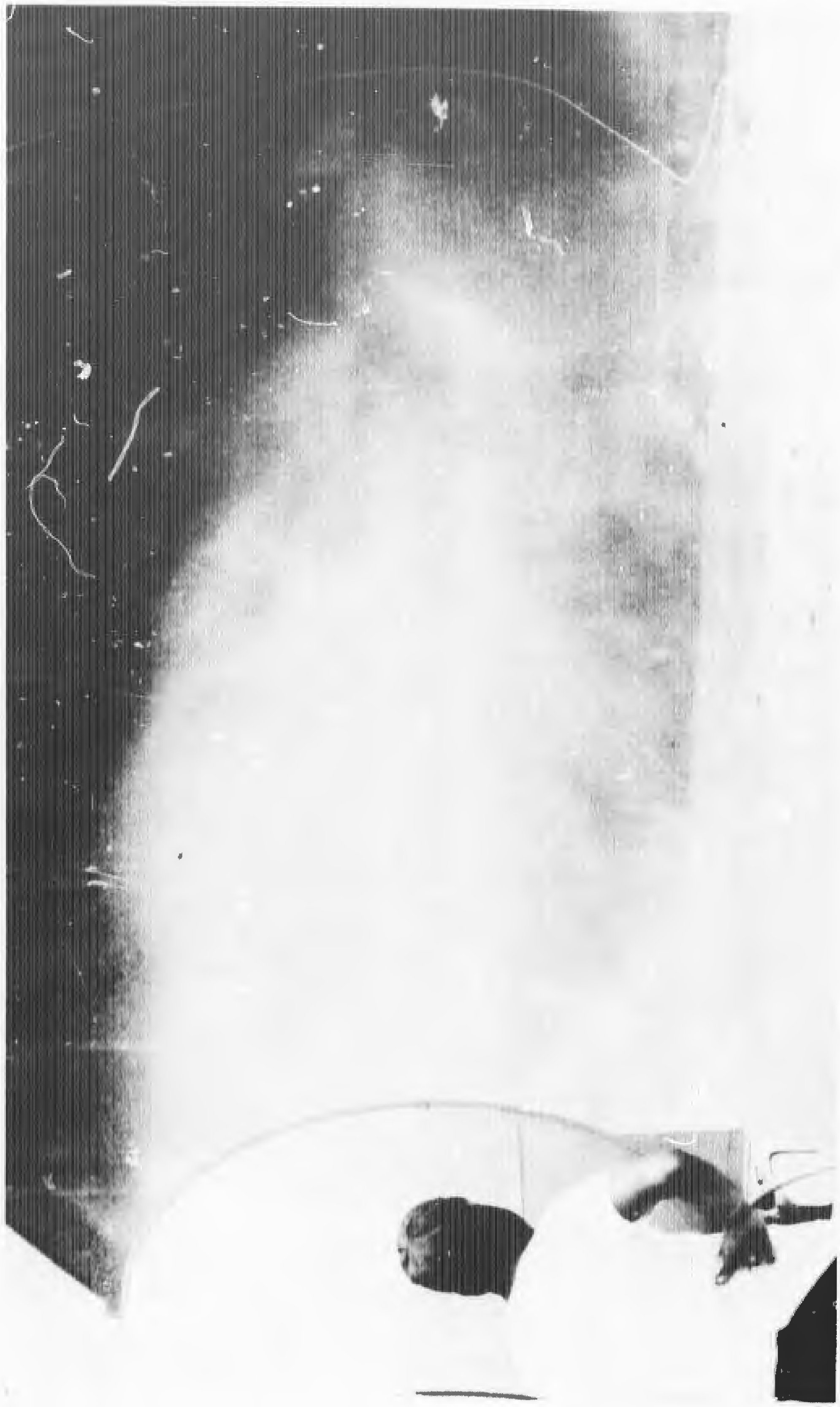


Figure 94 Metal Door During Wind/Rain Test

to the side or off of the ground skirt and allowed water to enter the shelter. Water pooled at the bottom of the doors when the sandbags were outside as it did in the fabric door test, but it was not able to be blown freely into the shelter (Figure 95). The panel-to-panel connection on the metal end wall and the panel-to-beam connections where the piano hinges were located had been

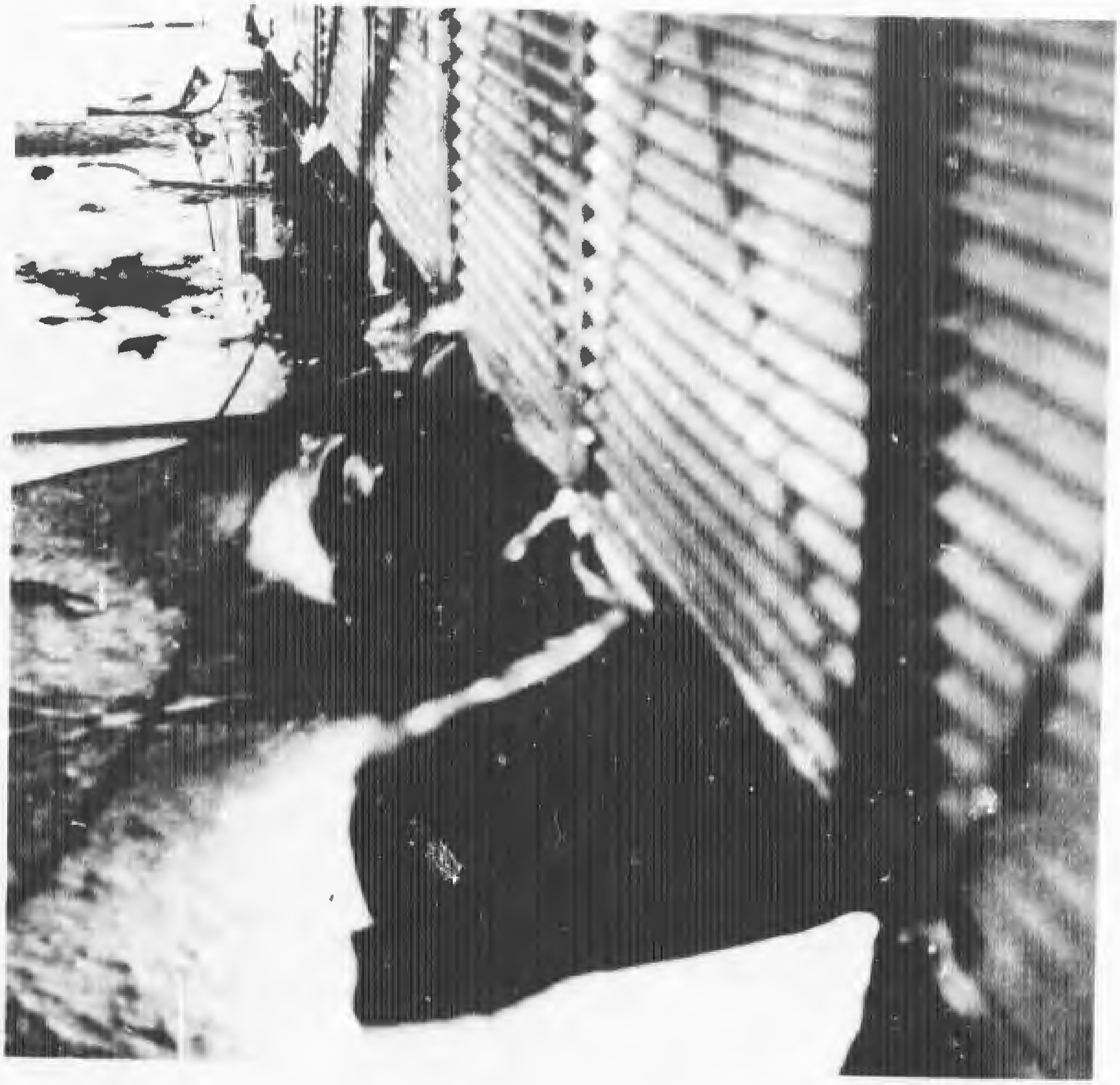


Figure 95 Water Leakage Under Metal Door and Ground Skirt Being Blown Inward

fitted with the weather stripping to retard the entrance of water. This design worked effectively and no leakage was observed. The end closures at the extreme sides of the shelter showed some signs of leakage because the doors did not fit securely into the frame provided. Some water was observed entering the top of the arch where the closure panel was installed, but this is because the wind machine was directed up at the area. In a normal rainfall, this area would not be subjected to such conditions. Overall, the building performed quite well during the rain tests, with the exception of water flowing underneath the door on both ends, and entering the personnel door on the fabric end wall. The problem that had been observed before, that of water coming into the shelter at the panel to arch connection, was prevalent during these test. Suggested correction of this problem will be discussed in Section VII.

SECTION VII

DISCUSSION OF SHELTER ERECTION AND TEST RESULTS

1. General. During the preceeding narrative, the components and parts of the facility were discussed as to the problems that arose during the particular phase that the shelter was undergoing. Comments were addressed pertaining to difficulities encountered during the erection, disassembly and testing. Several suggested modifications were also recommended. The items discussed in this section will center on the major components of the building as to their feasibility, adaptability, suitability and operational capability for the shelter and the recommended changes or modifications to the design.

2. Container. As discussed previously, the shelter in its final 88 ft configuration is designed to be packaged in four of the 8' by 8' by 10' containers. The containers would serve as the entry and exits of the shelter, and for storage of handtools, electrial service supply point and other miscellaneous items. If the metal end wall was utilized in the final design for the shelter, the containers would also serve as a anchoring platform for the large area of the doors that would be exposed to the wind when opened. The containers are quite expensive, and if deemed necessary they could be used to ship the building and then reentered into the transportation system to transport other types of material while the building is in the erected configuration.

The building components can also be transported on pallets as shown in Figure 12. The size of the panels and the arch beams are

8 ft long and fit very well on pallets and can be very easily banded. Some damage could be expected to the edge members on the panels due to the frailty of the extrusions at the locking joint.

3. Erection System. The A-frame gantry worked extremely well after it was assembled. The telescoping mast in the gantry system would allow the arches to be picked up at a higher point on the arch and possibly negate the requirement for the double arch beams to support the fabric door. The components of the gantry should be manufactured with interchangable parts. Lockpins should be used as the connection mechanism.

4. Base channels. The base channels were very effective in their assembly and operation during both erections. The flexibility in assembling the base rails and their ability to absorb uneveness in the ground added greatly to their effectiveness. Because of the loading at the extreme ends of the base rail while erecting the fabric door and metal door, a modification to the base channels could be implemented by placing a flat plate underneath the bottom of the end base channels to spread the load during the erection. A piece of 2x6 was used during the shelter erections and proved to be quite effective. The anchor systems for the base channels could vary depending on the type of soil where the building was to be erected. As previously described in the second erection phase, the arrowhead anchor on each side of the base channel proved to be quite effective. The same type of anchoring could be used on the anchor plates and guide rail for the vertical supports for both the fabric and metal end

wall. In contingency situations, minimum anchoring on the inside of the shelter should be accomplished to reduce the total erection time of the shelter. Additional anchoring could be provided after the building has been erected. To prevent the base channel from spreading during erection, a piece of cable 3/8 to ½ inch should be used to tie the base channels together at the predetermed distance. This would prevent the base channel from spreading and the follow-on problems of installing the panels between the archs.

5. Arch Beams. The arch beams performed well in most all phases of the test program. Some difficulty was experienced in assembling and disassembling the arch beams with the erection pins but to no great degree. The field modification that was made by Lockheed Georgia Co. by extending the cutout in the arch beam to allow the entry to more water should be accomplished on all the arch beams.

6. Arch Panels. The arch panels were very light weight and easy to handle, but the thin alumimum face sheet made them susceptible to damage. Punctures in the face sheet could cause problems with water migration and create further degradation to the structual capability of the panels. The corner inserts on the panels did suffer minor damage in some cases during the test. The fact that these inserts were only at the corners did allow entry of water into the shelter. The inserts should be extended the full length of the panel to ride on the track, thereby preventing water leakage into the shelter.

The locking joint that connects the panels should be strengthened to reduce its susceptibility to damage. The design of the lock joint

also has a tendency to accumulate water where the joint would be facing upward on one side of the building. Re-design of the lock system could improve the capability of the panels. The panels did undergo extreme deflections as a result of the loading prescribed in the statement of work. When unloaded, distortion still remained in the panels. Some type of structural stiffeners could improve the panels' resistance to deflection.

7. Fabric End Wall. The vertical supports for the fabric door fabricated under the contact were larger than required and hence added additional weight to the door. The method of attaching fabric to the vertical supports could be improved by using a heavy duty zipper rather than the grommets. This would reduce the time required to attach the fabric to the vertical posts greatly, and also negate the punctures that appeared in the fabric as a result of the screws on the back of the grommets. The opening and closing method on the fabric door was very complicated because of the two winches and the cable being strung through the different segments of the door. The whole operational mode of the door could be improved by a redesign to allow for the door to open and close at a faster rate. The horizontal travel of the vertical support beams to the track entry positions and pivoting from that point to the full open position worked well. The method of moving the supports was not satisfactory. The binding of the vertical supports could be reduced by attaching a guide rail to the upper roller beam to prevent the supports from twisting. The door

in its full open position provides a clear span of 38 ft 6 inches at the 10 ft height. The closure panels at the top of the guide rail that fill in the arch on both the metal and fabric end wall could be improved and a better attaching method designed. The ground flap could also be modified by installing zippers or snaps where it junctions at the vertical supports. In high winds this opening could be secured and then sandbags placed on the flap to prevent the entry of dust debris. The anchor plates were satisfactory and presented no problem during the tests. Some sort of locking mechanism to tie the fabric door vertical supports at the center should be included to insure that they come together for a close tight fit. The method of attaching the container to the shelter did allow some leakage of water. More weather stripping should be provided to prevent this problem. The personnel entry door in the end closure panel should be stiffened both in the fabric and in the door to provide a firm seat for velcro strips. With this modificiation, the door could be securely attached and prevent the leakage of water.

8. Panel Installation. The panel installation winch proved to be unsatisfactory during the assembly and disassembly operation. It was undersized and not of sufficent strength to endure the rigors it was to undergo. In all, the winch broke five times and was repaired locally. The cable on the winch broke six times, and required replacement. The method of pushing the panels up on the track with the puller bar caused

a great deal of difficulty because of the angle at which the force was applied. The further the panel went onto the arch the more deflection occurred (Table IX).

TABLE IX

Panel Deflection During Installations

PANEL NUMBER	POSITION DURING WINCHING	DEFLECTION (inches)
7	1/3	1/2
7	2/3	3/4
7	in place	7/8
12	1/3	5/8
12	2/3	1 1/2
12	in place	2 1/8
17	1/3	1 1/4
17	2/3	2
17	in place	2 1/4

A method should be devised to spread the load evenly along the entire bottom length of the panel between the archs, and to apply a force directly along the angle of the arch beams rather than pushing up and pulling in simultaneously.

9. Side Entry. All aspects of the side entry system worked well on the shelter with the exception of water leakage during the rain test. Additional sealant should be provided around the entire perimeter of the vertical panel where the corrugations intersect with the vertical and horizontal framing. The space above the door could be reduced somewhat and a positive sealing method provided. The overhang on the side

entry would prevent rain from coming in along the top of the door and the top of the vertical panel, but blowing dust and debris could enter the shelter in these areas.

10. Window Panels. The window panels were observed to be very effective. They allowed the passage of sufficent light and could be located anywhere within the arches. No leakage or damage was incurred to these particular panels during the entire test program.

11. Metal End Wall. The metal doors provided a good access area both in the truck entry and full open position. The difficulty in moving the doors along the upper rail because of the binding of the vertical beams presented a great deal of difficulty and required high reach equipment to loosen the beams in the rail. If the binding could be overcome, the doors were much quicker opening and closing than the fabric door, but more susceptible to damage from bumping or punctures. Repair of the corrugation would be much more difficult then pasting a patch on the fabric. The number of components utilized to make up the entire door was excessive as shown in the Appendix. Each part was designed to fit in a specific place with almost no interchangeability available. The piano hinges on both the door panels and vertical beams were totally unsatisfactory. A slight bump on the hinges could easily distort them and cause extreme difficulities in assembling the doors. The tight fit of the panel between the vertical beams and the attached weather stripping was sufficent to secure them against leakage.

The side closures in the end wall did not fit properly and allowed the

passage of water during the rain test. Closer tolerances should be used in the fabrication of these closure panels.

The Lockheed Georgia Co. conducted laboratory analysis on various components of the shelter during the fabrication phase of the project. The results of the Lockheed test program were published in an unnumbered technical report in March 1974.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions.

a. Basic design concept for the aircraft shelter presented a fresh new approach to solving the problems that had been inherent in past air transportable shelters.

b. Some of the component systems for the shelter functioned extremely well, particularly the erection system for the end closure and arch beams, the base channels and the beam and panel concept for tieing the arch beams together.

c. Specific items in the shelter system that required improvement are as follows:

(1). The panel installation winch was unsatisfactory. Also, the angle that the panels are pushed into the arch caused difficulty because the force pulls in and up rather than pushing the panels up along the curvature of the arch beams.

(2). The opening and closing method of the fabric door requires improvement. The method of turning the winches to draw the door open and closed is cumbersome and time consuming.

(3). The honeycomb core aluminum panels are highly susceptible to damage during erection and handling. Also, the locking joint and the panel-to-panel connection could be improved.

(4). Although the metal door functioned well when the binding in the top rail was not experienced, it proved unreliable during the test program.

(5). The basic components of the shelter, i.e. the panels, arch beams and base channels, provided a great deal of flexibility in assembling the building. There were too many one-of-a-kind parts that were required for the assembly of both the metal and fabric end wall. Interchangeability of components is desired, rather than having a specific part go in a designated place.

(6). During the test program, the need arose several times to enable personnel to get on top of the building. The present system, as designed, does not have a provision to accomplish this.

2. Recommendations.

a. The arch panels should be redesigned to provide a more durable panel with another type of lock mechanism at the panel-to-panel joint. The panel inserts should be provided on the full length of the panel that travels on the arch beam track to preclude entry of water.

b. The panel installation system should be modified to provide a heavier winch to install the panels and the panel puller bar should be modified to more evenly distribute the force required to push the panels into the arch and at an angle parallel with the angle of the arch beams.

c. Heavier cables should be provided in the layout system for the base channels to hold the channels in place during the erection of the first end wall and subsequent arch beams.

d. The opening and closing system for the fabric door should be revised to provide an easier and faster opening method.

e. If the reliability of the metal end wall could be improved where the door travels in the overhead rail, this door would provide a much faster opening method then the fabric door as currently designed. The piano hinges between the panels and the vertical posts were totally unsatisfactory and should be replaced with another means of securing the panels. Also, interchangeability among the door components would greatly improve the assembly procedure.

f. In the event the containers would not be required for the entry and exit for the shelter, it is recommended that two A-frame ganties be provided for the erection of the shelter. The pickup point on the end walls and arches should be raised to a higher point on the arch to reduce the number of arch beams and special pins required.

g. With the design changes stated herein, procurement of the LocArch shelter system is recommended.

NOTE:

The Air Force Civil Engineering Center is currently procuring a similar LocArch shelter for the Navy from the Lockheed Georgia Company. The contract requirements have incorporated many of the recommendations stated.

APPENDIX

Basic Component Parts List

	QTY.
END BASE RAIL	4
STD. BASE RAIL	14
GROUND BEAMS	9
STD. BEAMS	98
CENTER BEAMS	9
HONEYCOMB PANELS	185
GROUND FLASHING	15
TENSIONER	30
ARCH RESTRAINTS	2

FABRIC DOOR

	QTY.
FABRIC DOOR COLUMN FD1	10
FABRIC DOOR COLUMN FD2	2
FABRIC DOOR COLUMN FD3	8
FABRIC DOOR COLUMN FD4	2
FABRIC DOOR COLUMN FD5	6
FABRIC DOOR COLUMN SC1	1
FABRIC DOOR COLUMN SC2	1
FABRIC DOOR COLUMN SC3	1
FABRIC DOOR COLUMN SC4	1
FABRIC DOOR LEFT	1
FABRIC DOOR RIGHT	1
FABRIC DOOR TROLLEY BEAM FT1	2
FABRIC DOOR TROLLEY BEAM FT2	1
FABRIC DOOR FS	2
FABRIC DOOR TOP COVERING LEFT SIDE PANEL	1
FABRIC DOOR TOP COVERING MIDDLE PANEL	1
FABRIC DOOR TOP COVERING RIGHT PANEL	1
RIGGING WINCHES LEFT	1
RIGGING WINCHES RIGHT	1
FABRIC DOOR CLEVIS GROUND PLATE CP1	2
GROUND PLATE GP1	15

METAL DOOR

		QTY.
METAL DOOR	MDP 1	1
METAL DOOR	MDP 2	1
METAL DOOR	MDP 3	1
METAL DOOR	MDP 4	1
METAL DOOR	MDP 5	1
METAL DOOR	MDP 6	1
METAL DOOR	MDP 7 OR MD 7	1
METAL DOOR	MDP 8 OR MD 8	1
METAL DOOR	MDP 9 OR MD 9	1
METAL DOOR	MDP 10 OR MD 10	1
METAL DOOR	MDP 11 OR MD 11	1
METAL DOOR	MDP 12 OR MD 12	1
METAL DOOR	MDP 13 OR MD 13	1
METAL DOOR	MDP 14 OR MD 14	1
METAL DOOR	MDP 15 OR MD 15	1
METAL DOOR	MDP 16 OR MD 16	1
METAL DOOR	MDP 17 OR MD 17	1
METAL DOOR	MDP 18 OR MD 18	1
METAL DOOR	MDP 19 OR MD 19	1
METAL DOOR	MDP 20 OR MD 20	1
METAL DOOR	MDP 21 OR MD 21	1
METAL DOOR	MDP 22 OR MD 22	1
METAL DOOR	MDP 23 OR MD 23	1
METAL DOOR	MDP 24 OR MD 24	1

METAL DOOR (CONT'D)

	QTY.
METAL DOOR COLUMNS A1	1
METAL DOOR COLUMNS A2	1
METAL DOOR COLUMNS A3	1
METAL DOOR COLUMNS B1	1
METAL DOOR COLUMNS B2	1
METAL DOOR COLUMNS B3	1
METAL DOOR COLUMNS C1	1
METAL DOOR COLUMNS C2	1
METAL DOOR COLUMNS C3	1
METAL DOOR COLUMNS D1	1
METAL DOOR COLUMNS D2	1
METAL DOOR COLUMNS D3	1
METAL DOOR COLUMNS E1	1
METAL DOOR COLUMNS E2	1
METAL DOOR COLUMNS E3	1
METAL DOOR COLUMNS F1	1
METAL DOOR COLUMNS F2	1
METAL DOOR COLUMNS F3	1
METAL DOOR COLUMNS G1	1
METAL DOOR COLUMNS G2	1
METAL DOOR COLUMNS G3	1
METAL DOOR COLUMNS H1	1
METAL DOOR COLUMNS H2	1
METAL DOOR COLUMNS H3	1

METAL DOOR (CONT'D)

	QTY.
METAL DOOR TROLLEY MT1	2
METAL DOOR TROLLEY MT2	2
METAL DOOR TROLLEY MT3	2
METAL DOOR TROLLEY MT4	2
METAL DOOR TROLLEY MT5	1
METAL DOOR MS	2
METAL DOOR TOP COVERING LEFT SIDE PANEL	1
METAL DOOR TOP COVERING MIDDLE PANEL	1
METAL DOOR TOP COVERING RIGHT SIDE PANEL	1
METAL DOOR ERECTION FRAME EF1	1
METAL DOOR ERECTION FRAME EF2	1
METAL DOOR ERECTION FRAME EF3	1
METAL DOOR ERECTION FRAME EF4	1
METAL DOOR ERECTION FRAME EF5	1
METAL DOOR ERECTION FRAME EF6	1
METAL DOOR TRACK	10 Pieces
METAL DOOR SIDE CLOSURE LEFT	5 Pieces
METAL DOOR SIDE CLOSURE RIGHT	5 Pieces

SIDE ENTRY DOOR

	QTY.
SIDE ENTRY DOOR TOP	1
SIDE ENTRY DOOR UPPER LEFT SIDE PANEL	1
SIDE ENTRY DOOR LOWER LEFT SIDE PANEL	1
SIDE ENTRY DOOR UPPER RIGHT SIDE PANEL	1
SIDE ENTRY DOOR LOWER RIGHT SIDE PANEL	1
SIDE ENTRY DOOR LEFT FRONT PANEL AND DOOR	1
SIDE ENTRY DOOR RIGHT FRONT PANEL	1

PANEL WINCH

WINCH SUPPORT BAR	1
ATTACHED (1) LOCK	2
UPPER PULLEY BAR	1
LOWER PULLEY BAR	1
PANEL INSTALLATION BAR	1
PANEL REMOVAL BAR	1
WINCH BASE PAD	1

CONTAINER WINCH

CONTAINER WINCH	1
ATTACHED: CABLE STOP	
PULLEY SLIDE BAR	1
ATTACHED: (1) SPACERS	2
(2) ARCH SUPPORT STRAP	1

CONTAINER WINCH CONT'D

	QTY.
PULLEY POST	1
ATTACHED: (1) WINCH PIN	1
UPPER PULLEY PLATE	1
ATTACHED: (1) WINCH PIN	1
ERECTION WINCH SUPPORTS	1
STRUT LEFT	1
STRUT RIGHT	1
ATTACHED: (1) STRUT CONNECTOR	1
(a) WINCH PIN	1
WINCH BASE BAR	1
ATTACHED: WINCH PIN	2
CONTAINER LEVER	
CONTAINER LEVER	2
A-FRAME ERECTOR	
A-FRAME ERECTOR	17 Pieces
ATTACHED: ONE - CABLE STOP, TWO - SPACERS, ONE - ARCH SUPPORT STRAP	
ERECTION PINS	
"A" ERECTION PIN - COLOR NATURAL	190
"B" ERECTION PIN - COLOR BLACK	24
"C" ERECTION PIN - COLOR WHITE	2
"D" ERECTION PIN - COLOR YELLOW	2
"E" ERECTION PIN - COLOR NATURAL	4
"F" ERECTION PIN - COLOR GREEN	6
"G" ERECTION PIN - COLOR BLUE	8
"H" ERECTION PIN - COLOR ORANGE	2

ERECTION PINS CONT'D

	QTY.
ERECTION PIN REMOVAL TOOL - COLOR YELLOW	1
HINGE PIN REMOVAL TOOL (PACKED WITH "E" ERECTION PINS)	8 Pieces
ERECTION PIN RETAINERS	1 Box

463L ADAPTER

463L ADAPTER	2 Pieces

MISCELLANEOUS HARDWARE

MISCELLANEOUS HARDWARE	1 Box
JACKS, PLASTIC - COLOR YELLOW	11